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**INTEGRATED MANAGEMENT SOLUTIONS FOR POWDERY SCAB OF SEED AND TABLE POTATOES**

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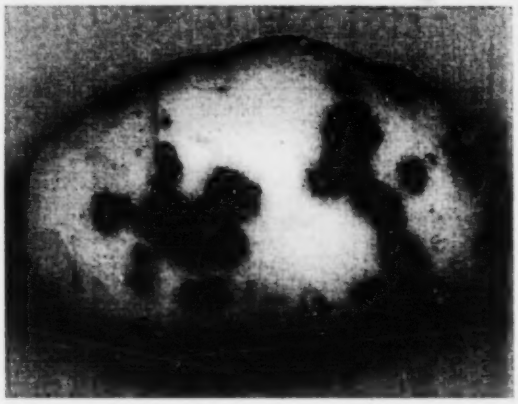

# Integrated Management Solutions for Powdery Scab of Seed and Table Potatoes

**ADF Project # 20020172**

**Final Report - February 2006**

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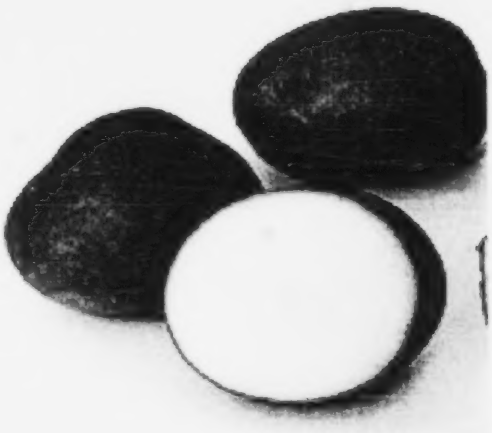

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## 1. ABSTRACT/SUMMARY

Powdery scab (*Spongospora subterranea*) has the potential to reduce the market value of both seed and table potatoes in Saskatchewan as this pathogen produces unsightly blemishes on the surface of harvested tubers. Most popular potato varieties are at least somewhat sensitive to attack by powdery scab. Crop rotation does not control powdery scab and there are no chemical control products presently registered for control of this disease in Canada. Different disease management strategies were evaluated for control of powdery scab in controlled environment and field trials from 2003-2005. The impact of these management strategies on two other significant soil-borne potato diseases (common scab (*Streptomyces scabies*) and black scurf (*Rhizoctonia solani*)) was evaluated simultaneously. In trials conducted in 2003 and 2004, manipulation of irrigation affected levels of all three diseases. Heavy irrigation, particularly at tuber set often increased yields – but also increased the incidence and severity of grade-out due to powdery scab. By contrast, lower soil water potentials at tuber set reduced yields and also increased grade-out to common scab. The optimum irrigation regime will depend on the nature of the scab infestation facing the grower. The new cultivar Gem Star appeared to be highly resistant to all types of soil-borne pathogens, while the newly released AC Peregrine appears more sensitive to scab than the previous standard Norland. Common and powdery scab were not controlled by seed piece applied fungicides. However, in-furrow and at hilling applications of two non-registered fungicides (Ranman and Blinex) appeared to reduce both the incidence and severity of infection by both scab organisms. Azoxystrobin (Quadris) applied in-furrow reduced the incidence of black scurf on the harvested tubers. Use of green manure crops has been suggested as a means to reduce problems with soil-borne potato diseases. Field and greenhouse tests conducted using various *Brassica* species as green manure showed some disease suppression but the effects were limited and/or inconsistent. Growth chamber studies indicated that the length of time between incorporation of green manure crops and planting of the potato crop may influence disease development. The level of disease control achieved in the green manure trials would not be sufficient to justify the effort or expense in establishing and maintaining the green manure crops. Mustard meals have been suggested as an alternate source of the glucosinolates that serve as biofumigants. Preliminary tests conducted under field and growth chamber conditions again suggest that the mustard meal may have some potential to suppress certain diseases, particularly if they are applied close to the time of tuber initiation.

## 2. EXECUTIVE SUMMARY

Many soil-borne diseases have the potential to reduce yields and crop value of the seed and table potatoes being grown in Saskatchewan. Powdery scab (*Spongospora subterranea* (Wallr.) Lagerh. f. sp. *subterranea* J.A. Tomlinson) and common scab (*Streptomyces scabies* (Thaxter) Lambert & Loria) are particularly problematic. Both of these pathogens are already fairly widespread in potato fields across Saskatchewan. Once established in a field, these pathogens are difficult to control by crop rotation as they either form long lived resting spores (powdery scab) or they have a wide host range

and the potential to survive as a saprophyte (common scab). There are no chemicals presently registered in Canada for control of either of these diseases. Potato cultivars vary in their sensitivity to scab – unfortunately many of the cultivars presently favored by Saskatchewan's seed and table growers are quite scab sensitive. Concerns about the potential for introduction of either powdery or common scab via infected seed also have the potential to restrict market options available to seed growers who happen to have either of these organisms established on their farm. Black scurf (*Rhizoctonia solani* Kuhn (teleomorph *Thanatephorus cucumeris* (A.B. Frank) Donk)) also causes cosmetic problems on harvested potatoes. This pathogen is also widely distributed throughout Saskatchewan and is only partially controlled by available pesticides. Saskatchewan-based growers attempting to sell seed potatoes into Mexico are experiencing significant problems meeting standards for freedom from *Rhizoctonia*. Development of integrated pest management strategies for control of these diseases would be beneficial to Saskatchewan potato producers.

A number of disease control methods were evaluated in trials conducted from 2003-2005 using a field site naturally infested with powdery scab, common scab and *Rhizoctonia*. Modification of the irrigation regimes affected levels of all three diseases in trials conducted in 2003 and 2004. Application of higher than normal amounts of irrigation at tuber set, and/or throughout the season, reduced the incidence of both common scab and black scurf. However increased irrigation also increased the incidence of powdery scab. The extent of the disease response to irrigation varied between cultivars. Manipulation of irrigation appears to have potential for use in disease management – but the irrigation regime will need to match the specific disease situation facing the grower. The 2005 irrigation trial failed to generate any useful data due to a failure in the irrigation regimes.

Six commercial cultivars were evaluated for their relative disease sensitivity. Norland was most severely infected with powdery scab on tubers and also developed the most powdery scab root galls. Norland, Russet Burbank and Gem Star were less susceptible to common scab than Russet Norkotah, AC Peregrine and Yukon Gold. Gem Star was also less susceptible to black scurf than the other cultivars tested.

None of the seed-applied fungicidal products produced a significant level of disease control. In-furrow and at hilling application of two non-registered products (Ranman and Blinex) produced excellent levels of control of powdery scab and were also useful against common scab. In-furrow applications of azoxystrobin and dithane reduced levels of black scurf on Penta tubers, but not on Norland. Azoxystrobin is registered for control of *Rhizoctonia* problems and should be a valuable product for producers.

Green manure crops have the potential to suppress certain soil-borne diseases. Four green manure crops (*Brassica juncea, B. napus, Sinapis alba, Lolium multiflorum*) were established in mid-summer of 2004. After six weeks growth, the green manures were ploughed under and potatoes were seeded into the plots in 2005. The green manure treatments had little impact on levels of any of the diseases monitored in this trial. The amount of disease control observed was not sufficient to warrant the effort and expense involved in generating the green manure crop. In growth chamber trials the time interval

between incorporation of green manures and planting of the potato crop appeared to influence pathogen levels. Further testing is necessary.

The glucosinolates present in members of the mustard family have been shown to serve as biofumigants. The potential to control disease by incorporating mustard meal rich in glucosinolates into the planting rows or hills was evaluated in growth chamber and field experiments. The meals appeared to suppress certain diseases, in certain situations – but in other situations they appeared to either suppress yields and/or exacerbate disease problems. The type of meal applied and the timing of application appeared to have some impact on disease development. Further evaluation of mustard meals is necessary.

None of the control strategies tested alone gave complete control of the soil-borne diseases that attack potatoes growing in Saskatchewan. An integrated approach, using a combination of control methods remains the only viable control strategy.

## 3. TECHNICAL REPORT

### 3.1. Background Information

The soil-borne diseases powdery and common scab (caused by *Spongospora subterranea* and *Streptomyces scabies* respectively), and black scurf (*Rhizoctonia solani*) have been identified by potato producers of Saskatchewan as being both frequent and economically significant problems. These diseases cause significant economic losses due to reduced yields and/or increased grade-out. Both types of scab cause unsightly blemishes on the tuber surface that are unacceptable in today's table market (Figure 3.1.1). The presence of scab lesions on seed potatoes is also unacceptable – particularly as seed-borne inoculum is the primary means whereby these pathogens move from field to field. *Rhizoctonia* not only causes unsightly black patches on the tubers (Figure 3.1.2), but the fungal pathogen attacks roots, stolons and stems (Figure 3.1.3), reducing the movement of water and nutrients within the plant. This damage reduces yield and can cause changes in the size distribution of the tubers, resulting in a small yield of undesirably large tubers.

These three pathogens survive for long periods in the soil and are not controlled by standard rotations of four years or less. Powdery scab produces resting spores (cystosori) either in scab lesions (Figure 3.1.4) or root galls (Figure 3.1.5). These spores can survive in the soil for at least ten years, and a minimum rotation of six years is recommended for this pathogen. Common scab has a wide host range and can also survive for extended periods as a saprophyte. Crop rotation is therefore of limited value for control of common scab.

There are no potato cultivars that are truly resistant to these diseases, although some cultivars may be less susceptible than others. Unfortunately, many of the cultivars presently favored by Saskatchewan's seed and table growers are quite sensitive to these diseases. None of the chemical control products presently registered for use on potatoes in Canada provides any significant degree of control of either of the scab diseases. Some

products, such as Maxim, reduce the problems with *Rhizoctonia* attacking the developing stems, but growers observe that this treatment is costly, that the quality of control varies from season to season and that the product is of little use in controlling the development of black scurf lesions on the harvested tubers.

Integrated pest management (IPM) programs use a variety of techniques including manipulation of the environmental conditions in which the crop is grown, use of resistant cultivars and application of pesticides, to reduce disease levels. As it is clear that no single control option is effective against scab or *Rhizoctonia*, an Integrated Management approach may represent the only viable option. Potential IPM techniques for control of powdery and common scab include modification of the soils by incorporation of organic matter from previous crops (green manuring) and the management of moisture levels by altering irrigation practices.

It was observed by G.B Sanford, as early as 1926, that the incorporation of green rye suppressed infection of subsequent potato crops by common scab (in: The Nature and Practice of Biological Control of Plant Pathogens, R.J. Cook & K.F. Baker, 1983). He suggested that the incorporation of the organic matter might have increased soil flora that were antibiotic to the scab pathogen. Incorporation of a green manure crop before planting a potato crop may alter the soil microflora, which in turn may reduce the number and/or infectivity of pathogenic organisms. Alternatively, the green manure may be directly fungistatic or fungicidal. This effect has been most widely reported following use of members of the *Brassicacea* as green manures. This family contains a range of potent biofumigants including mustard oils and glucosinalates. The potential to use green manure to manage powdery scab is not well documented.

The incidence and severity of both powdery and common scab are affected by soil moisture levels, particularly during early tuber set when both these pathogens invade the tubers through the thin skin and/or the lenticels. The powdery scab pathogen initially produces flagellate zoospores that infect the root hairs. *S. subterranea* then produces a second crop of zoospores that infect the roots and tubers. These zoospores depend on moisture for movement in the soil, thus low soil moisture at this period reduces the opportunity for infection to occur. Unfortunately infection by the common scab organism is favoured by the dry conditions that are most inhibitory to powdery scab infection.

Nonetheless, manipulation of irrigation schedules is an option for controlling scab, providing the grower knows which scab organism is likely to be the most problematic. Evaluation of the impact of irrigation treatments on both scab diseases is important to determine how producers can best modify their irrigation practices to control these diseases.

Information on the relative susceptibility of North American grown potato cultivars to powdery scab is sparse, as this disease has not been routinely assessed in cultivar evaluations. There is even less information on the relative sensitivity of cultivars on sites that contain both common and powdery scab.

Chemical controls are not presently a viable component of an IPM program for either common or powdery scab. Currently there are no fungicides registered in Canada for the control of powdery scab. Compounds tested in New Zealand, Australia, Britain and the United States appear to reduce levels of this disease. These products have not been evaluated under the conditions experienced by Saskatchewan producers.

No one method of control is likely to control diseases like *Rhizoctonia* and common and powdery scab, but a combination of control methods could be used to significantly reduce the impact of these diseases. The available disease management options will be evaluated individually in this project before the most promising are combined into an integrated pest management approach that is suitable for Saskatchewan production practices and growing conditions.

The specific objectives of this project are:

1) To separately evaluate control options for management of the key soil-borne diseases facing Saskatchewan potato growers – with a specific emphasis on powdery scab and to a lesser extent, common scab and *Rhizoctonia*.
2) To investigate combinations of effective control options
3) To assess the commercial viability of the resulting IPM program.

## 3.2. Materials and Methods

### 3.2.1. Study Site

A suitably infested site is crucial for carrying out disease evaluations in the field. Given the difficulty of controlling soil-borne diseases, producers do not encourage development of such sites on their land. At the University of Saskatchewan in Saskatoon we have created a field-testing site that is infested with common and powdery scab, as well as *Rhizoctonia*. The site is a sandy loam soil, with a pH of 7.9 and EC value of 1.5 $dSm^{-2}$. The field is approximately 15 acres and has been in a 3-year barley-barley-potato rotation for more than 20 years. The field is heavily manured with cattle and poultry manure except for the year immediately before potato production. Irrigation is provided with an overhead wheel move system.

This site provides an ideal venue for simultaneously studying all three diseases, and their interactions. Each pathogen responds differently to management practices and it is important to study both individual and combined responses to treatments.

Unless otherwise specified all trials were managed using conventional potato production practices. Cut seed tubers were planted between May 28 and June 9 using a single row planter. Spacing within the rows was 25cm with one metre between rows. Row lengths were 7 – 8m depending on the trial. All seed was E2 or E3, obtained from Saskatchewan except for Penta seed from Manitoba. Seed did not have any obvious scab infection but some *Rhizoctonia* lesions were always present. No seed treatments were applied except as specified in the chemical control trials. Rows were hilled twice, prior to and at

emergence. Weeds were controlled with herbicides and between-row tillage. No insect control measures were required. Unless otherwise specified, the plots were irrigated once soil moisture potential in the root zone fell below –60KPa. In the irrigation management trial water was applied using a drip irrigation system to achieve specific soil water regimes. No significant problems with other diseases were noted.

The trials were chemically desiccated at the beginning of September using Reglone and were ready for harvest the third week of September. A single row plot harvester was used. The harvested tubers were suberized at 15°C with high airflow for several weeks after harvest then cooled and stored at 5°C. Disease assessments were conducted by the end of December.

### 3.2.2. Data Collection and Statistical Analyses

Tuber samples were assessed from each row harvested. Tubers were washed under running water before being visually evaluated for the level of disease. The following data were collected, depending on the experiment and the pathogen being evaluated:

*Disease incidence* – the number of tubers infected with disease, expressed as a percentage of the total number of tubers sampled.

*Disease severity* – the % tuber surface infected was assessed visually for each tuber, using rating scales provided by the Canadian Food Inspection Agency. Disease severity was then expressed as the average % tuber surface infected for the total number of tubers in a sample.

*Percentage of tubers with >5% surface area affected* – the number of tubers with more than 5% of the tuber surface area infected was evaluated, expressed as a percentage of the total number of tubers sampled. This is an important level of disease development as tubers with more than 5% of the surface area infected are considered to be moderately diseased and only 5% of such tubers are allowed in either seed or Grade A table potatoes.

*Total yield* – total weight of tubers harvested from each row.

*Marketable-size yield* – the weight of tubers falling between 48 and 88mm in diameter, without taking into account grading-out due to disease infection.

*Marketable yield* – the weight of tubers of marketable size, falling between 48 mm and 88mm diameter, minus the weight of tubers removed because they would not meet the grading standards for disease levels.

*Rhizoctonia score* – the main stem/root of each plant was washed carefully and examined for the extent of *Rhizoctonia* infection. Roots were rated using the following scoring system:

| Score | Level of disease |
|---|---|
| 0 | healthy |
| 1 | lesions<15mm |
| 2 | lesions > 15mm but root/stem not girdled |
| 3 | stem/root girdled. |

*Gall score* - roots were carefully dug from the hills to be sampled. Stems with similar size root systems were selected. The roots were washed gently under running water. The number of powdery scab galls on each root system was evaluated using the following scoring system:

| Score | No. of galls/root mass |
|---|---|
| 0 | none |
| 2 | 1 |
| 4 | 2-3 |
| 6 | 4-10 |
| 8 | >10 |

This rating scheme was reported on the *Spongospora* web site at:
http://www.spongospora.ethz.ch/LaFretaz/scoringtablegalls.htm

In pot experiments all roots produced in one pot were carefully removed, washed, and rated using the same scheme.

*Plant biomass* – in the green manure field trial, 0.5 $m^2$ areas were selected at random in the plot, using a rigid metal square. All plants within the square were cut off at ground level and the fresh weight recorded immediately. Biomass/$m^2$ was reported.

*Disease levels* - levels of all three diseases were evaluated separately on each tuber. Common and powdery scab lesions can have a very similar appearance. Common scab lesions tend to be more raised and superficial, with an irregular outline. Powdery scab lesions are more circular, tend to be clustered in one area of the tuber, penetrate through the tuber skin, and have a slight rim of tuber skin around lesions that contain distinctive spore balls (cystosori). Lesions were examined carefully using a dissecting microscope for the presence of cystosori.

Data were analyzed using the SAS GLM procedure. When required, the data were transformed to reduce variance. Treatment means were compared using either Duncan's Multiple Range test or an LSD test, at $P$=0.10 or .05. Pre-planned single degree of freedom contrasts were used to clarify certain treatment effects.

## 3.3. Experiments Conducted

### 3.3.1. Impact of irrigation amount and timing on disease development

Previous field trials have indicated that both powdery and common scab are sensitive to the amount of water in the soil, particularly at tuber set. Common scab is favored by hot, dry conditions, while powdery scab is favored by cool, wet conditions at tuber set. Most potatoes in Saskatchewan are grown under irrigation – this provides the growers with the option to alter the soil moisture conditions in any manner that will reduce disease.

The objective of this trial was to determine if irrigation management could be used to minimize damage caused by these two diseases. The trials were conducted in the 2003-2005 growing seasons, the amount of water available to the crop was manipulated – and the impact of the water management regimes on yields and disease levels assessed. One of the key issues addressed was whether modification of the irrigation levels at tuber set was adequate, or was it necessary to adjust irrigation levels for the whole season.

**Materials and Methods:**

The trials were conducted in the 2003-2005 cropping seasons, using the same methods unless otherwise specified.

The differing irrigation regimes were achieved by positioning 1 or 2 drip irrigation lines (T-Tape, 0.9 gal/h/100' with 15 cm emitter spacings) along the tops of the rows (Figures 3.3.1.1 & 3.3.1.2). This allowed each row to be independently supplied with different amounts of water.

The five treatments in 2003 and 2004 were:

1. Normal irrigation - water applied whenever the moisture holding capacity within the effective rooting zone fell below -60 kPa. During a typical irrigation event, sufficient moisture was applied to return the effective root zone to field capacity (ca 2.5 cm of water).
2. Normal irrigation - except during the three weeks around tuber set when no moisture was applied.
3. Normal irrigation - except during the three weeks around tuber set when twice as much moisture as normal was applied.
4. Twice normal irrigation throughout the irrigation period.
5. No irrigation.

The irrigation regimes were initiated as the crop emerged at the end of June and continued until the end of August, by which time the crops had matured.

The reduced and extra irrigation at tuber set (treatments 2 and 3) were started on July 16$^{th}$ and ended August 4$^{th}$ in 2003, started July 16$^{th}$ and ended on August 5$^{th}$ in 2004, started July 19$^{th}$ and ended August 3$^{rd}$ in 2005.

The cultivars Penta and Norland were each planted in separate randomized complete blocks with five replications. Penta is a white skinned cultivar and Norland is red-

skinned. Both cultivars are considered to be susceptible to both scab diseases. A wider spectrum of cultivars was evaluated in the 2005 trial.

Soil moisture levels were monitored in one complete set of treatments using gypsum block tensiometers placed at 15 and 30 cm depths. Soil moisture monitoring commenced in mid-July, with readings taken twice weekly.

In mid-August two hills per row were carefully dug, and the roots of the plants examined for presence of *S. subterranea* galls. Average gall scores were determined for whole root systems. The percentage of tuber surface area infected with common and/or powdery scab was assessed on six tubers taken from the hills in 2004.

The trials were top killed using a chemical desiccant at the beginning of September and were harvested by late September or early October. Yields and disease levels on the harvested tubers were assessed using previously described methods.

In 2005 the trial was modified in an attempt to explore how modified irrigation regimes would influence disease levels and yields of a range of the potato cultivars commonly grown in Saskatchewan. The cultivars tested were:

Norland – standard red-skinned cultivar. Regarded as moderately disease resistant.

AC Peregrine – newly released red-skinned cultivar. Regarded as more disease sensitive than Norland.

Russet Norkotah – a high yielding russet line which is fairly disease sensitive

Gem Star - a newly released russet line with superior yield potential and processing characteristics. Gem Star also looks to be disease resistant.

Russet Burbank – standard russet variety – moderate yields but good disease resistance.

The trials were established in mid-May using certified seed. The trials were planted with a single row planter, with 20 cm between seedpieces within a row and 1 m between rows. Each treatment row was 8 m long and each treatment was replicated 5 times in a randomized complete block design.

In one of the treatments lime was added to plots seeded to Norland. Previous research had indicated that shifting the soil pH to >8.5 had the potential to reduce problems with scab.

The irrigation treatments were:

1) normal irrigation for the duration of the growing season
2) normal irrigation until tuber set – then irrigation stopped during tuber set – but irrigation resumed after tuber set
3) normal irrigation until tuber set – then double normal irrigation during tuber set – then normal irrigation resumed for the duration of the season.

Irrigation was initiated on July 19th, by which time tuber set had commenced, and the change in irrigation regime was initiated on August 3rd.

The crop was managed as previously described. Root samples were evaluated for powdery scab galls in late August. The trial was chemically desiccated in early September and harvested in early October. Disease evaluations were conducted as previously described.

**Results and Discussion:**

**2003 Trial.**

Powdery scab levels were significantly higher on tubers harvested from both cultivars when the soil was kept moist by applying twice the normal amount of irrigation throughout the season. There was also a significant increase in the amount of powdery scab on the Norland tubers that received extra irrigation during tuber set (Tables 3.3.1.1 and 3.3.1.2), suggesting this cultivar would be sensitive to the use of irrigation management as a common scab control strategy. Levels of powdery scab were generally higher on the Norland tubers than on Penta tubers. This is consistent with Norland being a susceptible cultivar.

**Table 3.3.1.1. Effect of irrigation regime on the percentage of harvested Penta tubers with >5% surface area affected by *Rhizoctonia*, common or powdery scab in 2003.**

| Irrigation Treatment | Av. % tubers with >5% surface area affected by disease: | | |
|---|---|---|---|
| | Rhizoctonia | Common scab | Powdery scab |
| Dryland | 28.4 a* | 95.2 a | 0.0 b |
| Normal | 12.6 b | 71.8 b | 0.6 b |
| None at tuber set | 12.6 b | 93.4 a | 0.0 b |
| 2X at tuber set | 10.4 b | 55.8 bc | 0.0 b |
| 2X all season | 15.0 b | 45.2 c | 6.6 a |
| *Coefficient of variance (%)* | *56.7* | *19.9* | *303.4* |

* means followed by the same letter are not significantly different using an LSD test. ($P$=0.05)

Common scab levels were significantly reduced on both cultivars when moisture was applied at higher than normal levels throughout the season or increased at tuber set only relative to the dryland and no moisture at tuber set treatments.

*Rhizoctonia* levels were reduced on the harvested tubers of both cultivars grown under all of the irrigation treatments, compared with tubers produced under dryland conditions.

Total and marketable size yields of Norland tubers were not influenced by the irrigation treatments (Table 3.3.1.3), indicating that the rainfall in 2003 was sufficient to supply adequate moisture to this cultivar. Totals yield of Penta tubers were significantly higher under the irrigation regime that kept the field wetter than normal throughout the season compared with dryland production. Yields of marketable size tubers under the high irrigation regime were also greater than under dryland conditions.

**Table 3.3.1.2. Effect of irrigation regime on the percentage of harvested Norland tubers with >5% surface area affected by *Rhizoctonia*, common or powdery scab in 2003.**

| Irrigation Treatment | Av. % tubers with >5% surface area affected by disease: | | |
|---|---|---|---|
| | Rhizoctonia | Common scab | Powdery scab |
| Dryland | 33.6 a* | 94.6 a | 0.0 b |
| Normal | 14.4 b | 61.8 b | 1.4 b |
| None at tuber set | 12.4 b | 67.2 b | 2.6 b |
| 2X at tuber set | 13.0 b | 27.0 c | 5.8 ab |
| 2X all season | 5.8 b | 22.6 c | 11.0 a |
| *Coefficient of variance (%)* | *52.7* | *31.4* | *132.0* |

* means followed by the same letter are not significantly different using an LSD test. ($P$=0 .05)

The yield of final marketable product is determined by not only the weight of tubers produced, but also by the extent of grade-out due to excess disease on the tubers. Tubers with more than 5% of the surface area infected are considered to be moderately diseased and only 5% of such tubers are allowed in either seed or Grade A table potatoes. As total yield of Norland was not influenced by irrigation, marketable yields under the high irrigation treatments would have been substantially reduced as these regimes significantly increased grade-out due to powdery scab. However the levels of common scab were dramatically reduced by the same increase in moisture levels - as a consequence increasing moisture would increase marketable yield of Norland if losses to common scab are dominant.

**Table 3.3.1.3. Effect of irrigation regime on the total and marketable yield of Norland and Penta cultivars in 2003.**

| Irrigation Treatment | Penta | | Norland | |
|---|---|---|---|---|
| | Total yield (kg/8m row) | Marketable size yield (kg/8m row) | Total yield (kg/8m row) | Marketable size yield (kg/8m row) |
| Dryland | 11.4 b* | 9.4 b | 16.8 a | 14.8 a |
| Normal | 14.0 ab | 11.6 ab | 21.0 a | 18.2 a |
| None at tuber set | 14.0 ab | 10.9 ab | 19.7 a | 17.1 a |
| 2X at tuber set | 15.9 a | 12.4 ab | 20.3 a | 17.3 a |
| 2X all season | 16.9 a | 13.3 a | 17.4 a | 14.8 a |
| *Coefficient of variance (%)* | *20.9* | *19.9* | *30.4* | *31.9* |

* means followed by the same letter are not significantly different using an LSD test. ($P$=0 .05)

For the cultivar Penta the highest grade-out due to powdery scab also occurred in the irrigation treatment that produced the highest yields. However, common scab disease

was far more of a problem than powdery scab on Penta and thus the high moisture levels would be preferable as they both increased yield and reduced common scab, resulting in the highest marketable yields.

**2004 Trial.**

Low numbers of galls were observed (0-5 per root system), on the plants sampled in August. There were no significant differences in gall populations between the irrigation treatments. At the August sampling very little powdery scab was observed on the tubers. There were however, significant effects of the irrigation treatments on levels of common scab on both cultivars. In the Norland plots the plants that received no irrigation throughout the season, as well as those that were drought stressed at tuber set, had significantly more common scab than tubers harvested from plots that were irrigated throughout the season (Table 3.3.1.4). In the Penta plots, plots with no irrigation at tuber set had significantly more disease than the plots that received twice normal irrigation throughtout the cropping season.

**Table 3.3.1.4. Effect of irrigation regime on the development of common scab on tubers sampled on August 18, 2004.**

| Irrigation regime | Average % of surface area infected with common scab on: | |
|---|---|---|
| | Norland tubers | Penta tubers |
| **Dryland** | 22.9 a* | 22.4 ab |
| **Normal** | 11.7 b | 19.2 ab |
| **None at tuberset** | 31.8 a | 24.2 a |
| **2X at tuber set** | 9.1 b | 17.5 ab |
| **2X all season** | 9.8 b | 11.5 b |
| ***Coefficient of variance (%)*** | ***45.3*** | ***49.6*** |

* means followed by the same letter are not significantly different using an LSD test. ($P$=0 .05)

By the final harvest, the incidence of common scab was very high for both cultivars (average incidence of 96.0% of tubers infected for Norland and 94.6% for Penta, Tables 3.3.1.5 and 3.3.1.6). This site has an extremely high inoculum load of *S. scabies*. Powdery scab levels were lower than common scab (average incidence of 4.1% for Norland and 10% for Penta) and were less uniform across the trial plots. Levels of powdery scab were higher in 2004 than in 2003 – the cool growing conditions in 2004 would be expected to favor powdery scab.

At the main harvest there were no significant differences amongst the various irrigation regimes for the level of infection by common scab in cv. Penta (Table 3.3.1.5). In the Norland plots the incidence of tubers with >5% common scab infection was significantly reduced when 2 X irrigation was applied throughout the season or at tuber set (Table 3.3.1.6).

**Table 3.3.1.5. Impact of irrigation management on the level of infection of harvested Penta tubers by black scurf, common and powdery scab in 2004.**

| Irrigation regime | Average % of tubers infected with: | | | Average % of tubers infected with >5% of: | |
|---|---|---|---|---|---|
| | Common scab | Powdery scab | Black scurf | Common scab | Black scurf |
| **Dryland** | 98.2 a* | 4.0 b | 84.0 a | 62.2 a | 10.0 a |
| **Normal** | 96.6 a | 19.4 a | 73.4 a | 64.6 a | 7.8 a |
| **None at tuberset** | 95.4 a | 10.0 ab | 85.2 a | 56.2 a | 11.8 a |
| **2X at tuberset** | 93.4 a | 10.0 ab | 71.4 a | 50.6 a | 8.0 a |
| **2X all season** | 89.4 a | 6.6 ab | 72.6 a | 54.8 a | 7.4 a |
| ***Coefficient of variance (%)*** | **7.9** | **112.5** | **15.9** | **30.3** | **76.4** |

* means followed by the same letter are not significantly different using an LSD test. ($P$=0.05)

**Table 3.3.1.6. Impact of irrigation management on the level of infection of harvested Norland tubers by black scurf, common and powdery scab in 2004.**

| Irrigation regime | Average % of tubers infected with: | | | Average % of tubers infected with >5% of: | |
|---|---|---|---|---|---|
| | Common scab | Powdery scab | Black scurf | Common scab | Black scurf |
| **Dryland** | 100 a* | 0.0 b | 90.6 a | 84.0 a | 9.2 ab |
| **Normal** | 98.8 a | 2.6 ab | 70.0 b | 77.2 a | 3.4 b |
| **None at tuberset** | 100 a | 2.0 b | 85.4 a | 90.8 a | 12.8 a |
| **2X at tuberset** | 95.4 a | 11.2 a | 82.6 ab | 53.2 b | 3.4 b |
| **2X all season** | 85.6 a | 4.6 ab | 82.0 ab | 41.4 b | 8.6 ab |
| ***Coefficient of variance (%)*** | ***6.3*** | ***165.9*** | ***13.3*** | ***17.0*** | ***90.9*** |

* means followed by the same letter are not significantly different using an LSD test. ($P$=0.05)

The irrigation management regimes also had a significant impact on the incidence of powdery scab in both cultivars at the final harvest. The least powdery scab was observed in the non-irrigated plots for Penta (Table 3.3.1.5). In the Norland plots, the lowest incidence of powdery scab occurred in the non-irrigated treatment and in the treatment where irrigation was reduced at tuber set (Table 3.3.1.6). Very few tubers of either cultivar developed more than 5% surface infection.

In cv. Norland, grade-out due to excessive black scurf was highest when irrigation was withheld at tuber set and lowest under normal irrigation and situations where irrigation was increased at tuber set (Table 3.3.1.6).

The results of the 2004 trial show that irrigation management is critical to managing both scab diseases. The 2004 findings were similar to the results seen in 2003.

The irrigation regimes significantly affected the total weight of harvested tubers for both cultivars and also the weight of tubers of marketable size for the Norland cultivar. In the Penta plots, the total yield from the non-irrigated treatment was significantly lower than from plots receiving the normal and twice normal irrigation treatments (Table 3.3.1.7). Non-irrigated treatments for Norland also produced significantly lower yields that treatments given extra water applied at tuber-set (Table 3.3.1.8). In both cultivars there were no significant differences between the irrigated treatments in either total or marketable size yields.

Seed and grade A table potatoes are allowed 5% of tubers that have more than 5% of their surface area infected with disease such as scab and black scurf. When the marketable yield was adjusted to consider tubers that would be graded out for exceeding scab disease tolerances, there were no significant differences between the various irrigation regimes for cv. Penta (Table 3.3.1.7). However for the Norland cultivar, when

**Table 3.3.1.7. Effect of irrigation management on total yield, yield marketable by size, and yield marketable after grade-out to common scab for Penta in 2004.**

| Irrigation regime | Average yield in kg/8m of row | | |
|---|---|---|---|
| | Total yield | Marketable size yield | Marketable yield aftergrade-out to common scab (% of marketable size yield) |
| **Dryland** | 26.7 b* | 23.6 a | 10.9 a |
| **Normal** | 32.4 a | 26.1 a | 10.8 a |
| **None at tuberset** | 29.0 ab | 23.5 a | 8.9 a |
| **2X at tuber set** | 31.2 ab | 27.4 a | 13.2 a |
| **2X all season** | 32.5 a | 25.7 a | 13.7 a |
| ***Coefficient of variance (%)*** | **12.8** | **17.3** | **39.3** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

**Table 3.3.1.8. Effect of irrigation management on total yield, yield marketable by size, and yield marketable after grade-out to disease for Norland in 2004.**

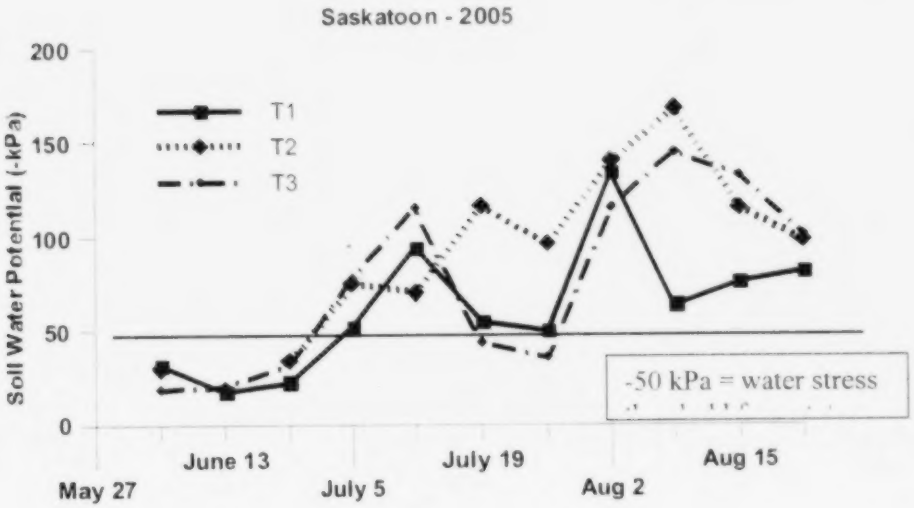
| Irrigation regime | Average yield in kg/8m of row | | |
|---|---|---|---|
| | Total yield | Marketable size yield | Marketable yield aftergrade-out to common scab (% of marketable size yield) |
| **Dryland** | 32.4 b* | 26.1 b | 5.5 b (21.1) |
| **Normal** | 40.9 ab | 30.5 ab | 8.3 b (27.2) |
| **None at tuberset** | 40.0 ab | 32.9 ab | 4.7 b (14.3) |
| **2X at tuber set** | 42.5 a | 32.7 ab | 17.0 a (52) |
| **2X all season** | 41.6 ab | 33.9 a | 22.3 a (65.8) |
| ***Coefficient of variance (%)*** | ***17.7*** | ***17.1*** | ***45.4*** |

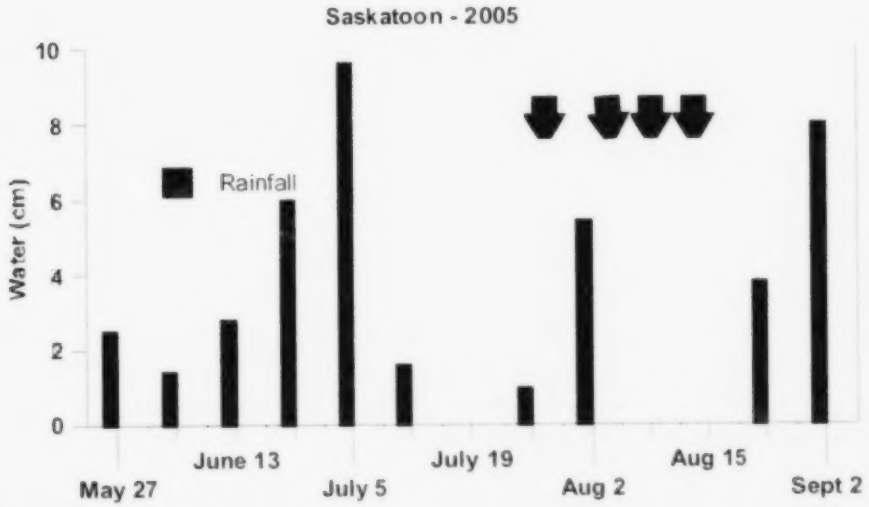
*means followed by the same letter are not significantly different (P=0.05), using the LSD test.

the irrigation regime was either twice normal or involved extra irrigation at tuber set, yields after grade out to disease were significantly higher than the other irrigation regimes. Over 50% of the marketable size tubers were still marketable after grade-out in plots receiving these higher levels of irrigation. In contrast, less than 25% of the tubers were marketable in the plots receiving no irrigation at tuber set or throughout the season. This confirms the observation that increasing moisture at tuber set is an effective way to reduce damage caused by common scab. Applying more water, particularly at tuber set, is highly recommended for fields where common scab is the dominant disease.

**2005 Trial.**

The 2005 growing season was cool and wet during May and June. Precipitation and temperatures were near normal in July and August. Crop establishment was slow but conditions were excellent during tuber set and bulking. 37 cm of rainfall was received over the growing season which is well above the norm of 20 cm. Frequent and heavy rain through June coupled with cool weather for the duration of the growing season reduced the overall requirement for irrigation for the main research plots. As the irrigation of the disease nursery plots is linked to irrigation of the main plots, the disease plots were only irrigated on 4 occasions in 2005. By contrast 6-8 irrigation events are required in a typical year. The drip irrigation lines used to supply water to this trial supply water relatively slowly – and they were not able to maintain soil water potentials at the desired levels in 2005. As shown in Figure 3.3.1.1, the nursery plots were well above the water stress threshold for potato from early July through until harvest. There were some differences in the soil moisture profiles generated by the various irrigation treatments – but the trial was nonetheless compromised by the failure to achieve the desired soil moisture levels.




= irrigation event

**Figure 3.3.1.1. Soil water potential and irrigation application during the 2005 growing season.**

The root assays showed no powdery scab galls in this trial, except for on AC Peregrine where a light infestation was observed. No powdery scab was observed on any of the tubers harvested in this trial. Given the drought stress that this trial encountered, the lack of powdery scab is not unexpected. Powdery scab thrives under cool wet soil conditions.

The incidence and severity of black scurf was highly variable in all treatments in this trial (Table 3.3.1.9). None of the irrigation treatments had any significant impact on the levels

of black scurf seen on any of the cultivars tested. Norland appeared to be far more susceptible to black scurf than AC Peregrine.

**Table 3.3.1.9. Influence of irrigation regimes on black scurf levels – 2005 trial**

| Irrigation Regime | Norland | Norland + Lime | Gem Star | AC Peregrine | Norkotah | Burbank | **Average** |
|---|---|---|---|---|---|---|---|
| | | | | **% of tubers infected** | | | |
| Normal | 45 | 54 | 10 | 8 | 31 | 20 | **28** |
| Deficit | 52 | 54 | 12 | 8 | 37 | 19 | **30** |
| Extra | 48 | 43 | 11 | 13 | 24 | 15 | **26** |
| **Average** | **48** | **50** | **11** | **10** | **31** | **18** | |

The incidence and severity of common scab was very high in this trial. This may reflect the fact that the trials were under drought stress for the majority of the growing season. Common scab is favored by dry conditions. None of the irrigation treatments had any significant impact on either the incidence or severity of common scab for any of the cultivars tested (Tables 3.3.1.10 & 11). Norland appeared to be far more resistant to common scab than was AC Peregrine. Addition of lime appeared to increase the incidence and severity of scab problems on Norland – this runs contrary to previous findings. Russet Norkotah was more scab sensitive than Russet Burbank or Gem Star.

**Table 3.3.1.10. Influence of irrigation regimes on common scab levels – 2005 trial**

| Irrigation | Norland | Norland + Lime | Gem Star | AC Peregrine | Norkotah | Burbank | **Average** |
|---|---|---|---|---|---|---|---|
| | | | | **% of tubers infected** | | | |
| Normal | 51 | 82 | 31 | 100 | 99 | 17 | **63** |
| Deficit | 65 | 83 | 19 | 100 | 91 | 17 | **62** |
| Extra | 45 | 74 | 34 | 100 | 92 | 9 | **59** |
| **Average** | **54** | **80** | **28** | **100** | **94** | **14** | |

None of the irrigation regimes had any significant impact on total yields or yields after grade-out due to excessive disease (Table 3.3.1.12).

**Table 3.3.1.11. Influence of irrigation regime on common scab severity – 2005 trial**

| Irrigation | Norland | Norland + Lime | Gem Star | AC Peregrine | Norkotah | Burbank | **Average** |
|---|---|---|---|---|---|---|---|
| | | | | **% of tubers infected with >5% scab** | | | |
| Normal | 2 | 28 | 8 | 93 | 55 | 2 | **31** |
| Deficit | 5 | 18 | 0 | 98 | 60 | 0 | **30** |
| Extra | 2 | 18 | 3 | 94 | 67 | 3 | **31** |
| **Average** | **3** | **21** | **3** | **95** | **61** | **2** | |

Yield of the later maturing (Russet Burbank) and drought stress sensitive (Russet Norkotah) cultivars were relatively low in this trial. This supports the concept of the trial having experienced a significant degree of drought stress.

**Table 3.3.1.12.Influence of irrigation regimes on total yields – 2005 trial**

| Irrigation | Norland | Norland + Lime | Gem Star | AC Peregrine | Norkotah | Burbank | **Average** |
|---|---|---|---|---|---|---|---|
| | | | | **Yields (t/ha)** | | | |
| Normal | 56.1 | 52.5 | 42.2 | 40.8 | 45.1 | 35.6 | **45.4** |
| Deficit | 58.0 | 55.0 | 41.8 | 42.9 | 43.0 | 42.0 | **47.1** |
| Extra | 56.5 | 53.8 | 39.8 | 46.9 | 50.5 | 37.4 | **47.5** |
| **Average** | **56.9** | **53.8** | **41.3** | **43.9** | **46.2** | **38.3** | |
| **Lsd** | 21.8 | 14.5 | 8.8 | 10 | 8.5 | 12.5 | |
| **CV (%)** | 27 | 18 | 15 | 16 | 13 | 24 | |

### 3.3.2. Susceptibility to disease of different potato cultivars

Susceptibility to disease differs between cultivars and the response of each cultivar varies under the differing conditions that occur from site to site and season to season. It is important for growers to be aware of the variation in disease response that may occur, in order to select cultivar most suited to their growing conditions and market needs.

In 2003 and 2004 trials were conducted to evaluate the relative susceptibility of a range of cultivars of potato to black scurf and both common and powdery scab. Cultivars selected for testing reflect the range of cultivars presently grown in Saskatchewan and any new cultivars with apparent promise.

**Materials and Methods:**

Certified seed was obtained from Saskatchewan and New Brunswick seed growers. The trials were conducted at the previously described disease nursery site in Saskatoon. All crop management and trial protocols were as previously described.

In 2003, five cultivars of potato were planted on May 30 in a randomized block design with five replicates. Each row was 8.5m long, to allow for sampling throughout the season. The potato cultivars planted were Andover, Norland, Russet Burbank, Russet Norkotah and Yukon Gold.

Samples of roots were collected from three plants of each cultivar on both August 18 and 30. The number of powdery scab galls per root was evaluated, and the roots were rated using the scoring system described in section 3.2.2.

In 2004, two new cultivars of interest to Saskatchewan growers were included in the trials. Gem Star is a new russet-type potato for processing and AC Peregrine is a red-skinned table potato exclusively available for sale by members of the Saskatchewan Seed Potato Growers Association. Other cultivars tested included Norland, Russet Burbank, Russet Norkotah and Yukon Gold. Andover did not show any resistance to disease in the 2003 trials – it was dropped from the 2004 trial.

The 2004 trial was conducted as a randomized block design with five replicates. Each row was 8m long. A sample of six stems/row was taken in early September before top-kill and the number of powdery scab galls per root system recorded. The amount of disease on the crop at the final harvest was assessed as previously described.

Yields were not taken from these trials.

**Results and Discussion:**

Norland tubers consistently showed the most severe powdery scab infection and the highest proportion of tubers with >5% of the surface area affected by this disease (Table 3.3.2.1). Andover and Yukon Gold also had significantly higher levels of powdery scab than the two Russet cultivars. There were no signs of powdery scab infection on the Burbank tubers. The powdery scab root gall score was significantly higher on the Norland plants than on the other cultivars at both sampling times (Table 3.3.2.1). At the mid-August sampling, Yukon Gold plants had significantly more root galls than the Russet Burbank roots that had not developed galls at this time. By the late August sampling Norland had significantly higher gall scores than the four other cultivars. A few galls had developed on the Burbank roots by this time.

**Table 3.3.2.1. Development of powdery scab on five different potato cultivars – 2003 trial.**

| Cultivar | Disease parameter: | | | | |
|---|---|---|---|---|---|
| | Gall score Aug 18 | Gall score Aug 30 | Av. % infected tubers | Av. % tubers with >5% infection | Av. disease Severity |
| Andover | 1.1 cb* | 1.9 b | 33.4 ab | 11.2 b | 0.8 b |
| Yukon Gold | 2.4 ba | 1.6 b | 19.8 ab | 6.0 b | 0.6 b |
| Russet Burbank | 0.0 c | 0.3 b | 0.0 c | 0.0 b | 0.0 b |
| Russet Norkotah | 0.6 cb | 0.1 b | 6.6 c | 2.0 b | 0.2 b |
| Norland | 4.2 a | 4.9 a | 47.0 a | 25.2 a | 2.5 a |
| *Coefficient of Variance (%)* | ***99.6*** | ***102.2*** | ***81.3*** | ***99.6*** | ***98.1*** |

*means followed by the same letter are not significantly different (P=0.05), using the LSD test.

Russet Burbank tubers showed very low incidence and severity of common scab infection (Table 3.3.2.2). Andover, Yukon Gold and Russet Norkotah tubers were all very susceptible to common scab, and should not be planted in scab infested soil.

**Table 3.3.2.2. Development of common scab on five different potato cultivars – 2003 trial.**

| Cultivar | Disease parameter: | | |
|---|---|---|---|
| | Av. % infected tubers | Av. % tubers with >5% infection | Av. disease Severity |
| Andover | 98.8 a* | 83.8 a | 14.1 a |
| Yukon Gold | 99.4 a | 88.4 a | 16.9 a |
| Russet Burbank | 3.8 c | 3.2 c | 0.8 b |
| Russet Norkotah | 95.2 a | 86.0 a | 15.1 a |
| Norland | 82.6 b | 44.4 b | 4.2 b |
| *Coefficient of Variance (%)* | ***10.3*** | ***22.9*** | ***44.0*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

There were no significant differences in the overall incidence of *Rhizoctonia* on the five cultivars tested (Table 3.3.2.3). Levels of *Rhizoctonia* were fairly high, and grade-out for this disease would be required on all except the Norland tubers. Yukon Gold tubers had the highest incidence of tubers with >5% surface area affected by *Rhizoctonia* lesions.

**Table 3.3.2.3. Development of *Rhizoctonia* on five different potato cultivars – 2003 trial.**

| Cultivar | Disease parameter: | | |
|---|---|---|---|
| | Av. % infected tubers | Av. % tubers with >5% infection | Av. disease Severity |
| **Andover** | 46.2 a* | 17.8 ab | 1.5 ab |
| **Yukon Gold** | 43.6a | 29.0 a | 2.1 a |
| **Russet Burbank** | 27.8 a | 11.8 ab | 0.8 ab |
| **Russet Norkotah** | 32.4 a | 11.2 ab | 0.9 ab |
| **Norland** | 29.8 a | 4.0 b | 0.5 b |
| ***Coefficient of Variance (%)*** | ***59.5*** | ***99.5*** | ***96.7*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

In this trial the Norland cultivar, an extremely popular red table potato, was most susceptible to powdery scab. It was also susceptible to common scab infection, but was the most resistant cultivar to *Rhizoctonia* infection. Russet Burbank was extremely resistant to powdery and common scab, but developed average levels of *Rhizoctonia*. Russet Norkotah developed more powdery scab than Russet Burbank, was susceptible to common scab and had average levels of *Rhizoctonia*. Yukon Gold was less susceptible to powdery scab than Norland, and showed high susceptibility to common scab and *Rhizoctonia*. Andover, a cultivar supposedly resistant to powdery scab, was similar to Yukon Gold for all three diseases. The disease reactions should be evaluated for several growing seasons, before recommendations can be made to growers concerning the suitability of cultivars to perform under high disease pressure.

**2004 Trial.**

Gall numbers were not high on the root samples taken in early September (<5/root) and low levels of disease were found on most tubers at harvest time. However, the red-skinned, scab-susceptible cultivars Norland and AC Peregrine had significantly higher numbers of galls than the other four cultivars (Table 3.3.2.4). Norland was the only cultivar with any appreciable level of powdery scab on harvested tubers. An average of 19% of the Norland tubers had powdery scab lesions, with 5% of the tubers having more than 5% of the surface area infected. Powdery scab infection was found on AC Peregrine tubers in only one replicate, and in this case 3 out of 30 tubers were diseased, with more than 5% of the surface infected. No powdery scab was observed on the other cultivars. AC Peregrine tubers appeared to be less susceptible to powdery scab than Norland, but disease evaluations should not be based on the results from one trial.

The incidence of black scurf was significantly lower on Gem Star than any other cultivar (Table 3.3.2.4). Both Gem Star and Norland had no tubers with >5% surface area infected by black scurf. Yukon Gold was the most severely affected by *Rhizoctonia*, with 24% of tubers having >5% surface area infected

**Table 3.3.2.4. Disease development on six potato cultivars in 2004.**

| Cultivar | % tubers with black scurf | % tubers with >5% black scurf | % tubers with common scab | % tubers with >5% common scab | Av. gall score/main root |
|---|---|---|---|---|---|
| **Norland** | 69.8 a* | 0.0 c | 85.6 ab | 13.0 c | 1.0 a |
| **Yukon Gold** | 65.0 a | 23.8 a | 94.2 a | 37.6 b | 0.1 b |
| **AC Peregrine** | 61.8 a | 14.2 ab | 100.0 a | 91.2 a | 1.5 a |
| **Gem Star** | 17.0 b | 0.0 c | 75.6 b | 15.0 c | 0.2 b |
| **Russet Burbank** | 65.2 a | 13.0 ab | 29.2 c | 3.8 c | 0.2 b |
| **Russet Norkotah** | 56.2 a | 5.6 bc | 93.8 a | 46.4 b | 0.0 b |
| ***Coefficient of Variance (%)*** | ***44.3*** | ***100.0*** | ***15.5*** | ***43.3*** | ***109.3*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

The incidence and severity of common scab was very high in this trial. The lowest incidence of this disease occurred on Russet Burbank tubers. Gem Star also had significantly lower incidence of common scab than Yukon Gold, AC Peregrine and Russet Norkotah (Table 3.3.2.4).

Reaction to the three diseases differed, thus the suitability of a cultivar to a specific field depends on the specific pathogens predominant in the field. For example, Norland was the only cultivar that developed appreciable levels of powdery scab in 2004, but it also developed the lowest levels of *Rhizoctonia* and was less sensitive to common scab than AC Peregrine. Both Norland and AC Peregrine formed significant numbers of powdery scab galls on the roots. This suggests that AC Peregrine may develop less powdery scab tuber infection and would be preferred as a red-skinned cultivar on sites infested with powdery scab. However, it also indicates that powdery scab inoculum pressure will increase even if AC Peregrine is grown – as the roots of AC Peregrine support development of the spore-laden galls.

Russet cultivars are generally more resistant to scab than red- or white-skinned cultivars. Gem Star and Russet Burbank appeared less sensitive to both types of scab than Russet Norkotah. Gemstar was also quite resistant to black scurf. The combination of high levels of disease tolerance plus good yields and processing quality suggests that Gem Star represents a very promising new variety.

### 3.3.3. Efficacy of fungicides applied at planting for control of disease

Seed treatments are routinely applied to potato seed tubers before planting to protect the seed piece from decay, thereby allowing establishment of a healthy stand. The effect of available seedpiece treatments on scab (powdery and common) is not known. Little benefit is anticipated due to the small amount of product applied, its isolation near the seedpiece and the significant time span between application and onset of the scab disease. In-furrow applications of fluazinam and mancozeb at planting have been shown to reduce the incidence of powdery scab in New Zealand (Falloon *et al.* 1994 – Treatments for Powdery Scab. New Zealand Commercial Grower 49(7): 10-11.) In-furrow application of azoxystrobin is registered for the control of *Rhizoctonia* diseases but the impact of this treatment on both scab diseases has not been reported.

In 2003 and 2004 four fungicide treatments applied at planting were assessed for their potential to control both scab diseases and *Rhizoctonia*.

**Materials and Methods:**

Four fungicide treatments were applied to Norland and Penta potatoes in a randomized block design with four replicates.

The fungicide treatments were:

1. No fungicide applied
2. Tuberseal (16% mancozeb, United Agri Products, 14g/50 seed pieces) applied as a dust on the seed
3. Tuberseal on the seed + in-furrow application of Quadris (250g/L azoxystrobin, Syngenta, applied at 1.6g product in 3L $H_2O$/24m row)
4. Tuberseal on the seed + in-furrow application of Omega (40% ai fluazinam, Syngenta, 1.9g product in 3L /24m row)
5. Tuberseal on the seed + in-furrow application of Dithane F45 (37% mancozeb, Dow AgroSciences, 36.2g product in 3L /24m row)

The in-furrow products were applied with a hand-held $CO_2$ driven sprayer, with the nozzle being held between the opener discs of the seeder, over the area where the seed dropped. All product rates correspond with label specifications.

The trial was managed in accordance with previously described procedures. The trial was harvested in late September and yields and disease levels were evaluated as previously described.

In 2005 several new products were added to the trial, which was managed using conventional production practices. Norland E2 seed was planted on May 27$^{th}$ in 6 m rows with 1 m between rows and 25 cm between seedpieces within the row. The treatments were arranged in a randomized block design with four replicates. Four side-by-side rows were used for each treatment. Root samples were taken from the outer rows and the two center rows were harvested and assessed for yield and disease.

3% of the tubers used to seed this trial had more than 5% of the surface infected with *Rhizoctonia*. No visible scab was present on the seed. Rows were hilled twice – once prior to emergence and again at emergence. Irrigation and weed control practices were as previously outlined.

Six fungicides were applied to the seed prior to planting, as an in-furrow treatment and/or at hilling. The Ranman and Blinix treatments made at hilling (second hilling = June 15$^{th}$) were applied at the same rate as was used for the in-furrow treatments applied at planting. The at-hilling treatments were sprayed as a 15 cm wide band over the top of the hill. The rows were hilled immediately after the spray treatment. A heavy thundershower occurred after hilling, which presumably washed the chemicals into the soil.

The fungicide treatments tested in 2005 were:

1. Allegro 500F applied as a liquid in-furrow (40% fluazinam, Syngenta, 5.25g product in 3L water/24m row)
2. Tuberseal applied as a dust on the seed (16% mancozeb, United Agri Products, 7g/25 seed pieces)
3. Dithane DG applied as a liquid in-furrow (75% mancozeb, Dow AgroSciences, 4.4g product in 3L /24m row)
4. Ranman 400SC applied as a liquid in-furrow at planting and prior to hilling (34.5% cyazofamid, ISK Biosciences, 12g product in 3L/24m row at both applications)
5. Blinix applied as a liquid in-furrow (8.5% Rhamnolipid Biosurfactant, Jeneil Biosurfactant Co., 6 ml in 3L/24 m row)
6. Blinix applied prior to hilling (same rate as treatment 5)
7. Check – no chemicals applied.

Three hills were dug from one row of each treatment/replicate in early September and the incidence of powdery scab galls on the roots was assessed. The roots from each individual stem were rated using the standard scoring system.

The crop was top-killed, harvested and evaluated for yields and disease levels utilizing the previously described methods. Disease assessments were conducted in November 2005.

**Results and Discussion:**

**2003 Trial.**

Levels of powdery scab infection in this trial were very low and it was not possible to evaluate the efficacy of the fungicides for control of this disease. Incidence and severity of powdery scab is not uniform across this nursery site. Whether this reflects non-uniformity of inoculum or differences in soil conditions has not been determined.

Adjacent trials had very high levels of powdery scab – indicating that growing conditions were suited to development of this disease.

Common scab levels were high in this trial, with over 90% of all Penta tubers developing disease (Table 3.3.3.1). Levels of common scab infection were lower in the Norland. There were no significant effects of any of the chemical treatments on common scab levels for either cultivar. This is not surprising as the chemicals applied were fungicides and would not be effective against common scab, which is caused by a bacterial pathogen. Nonetheless, some fungicides, for example Polyram (a.i. metiram), do claim to control seed-borne common scab.

**Table 3.3.3.1. Efficacy of fungicide treatments for the control of common scab on Penta and Norland tubers, 2003.**

| Fungicide Treatment | Penta | | Norland | |
|---|---|---|---|---|
| | % infected tubers | % tubers >5% sa[1] infected | % infected tubers | % tubers >5% sa[1] infected |
| **No fungicide** | 92.5 a* | 78.0 a | 63.0 a | 27.5 a |
| **Tuberseal (TS)** | 97.5 a | 74.5 a | 58.0 a | 18.0 a |
| **TS + Omega** | 97.5 a | 73.0 a | 64.0 a | 22.3 a |
| **TS + Dithane** | 95.8 a | 79.0 a | 46.5 a | 15.8 a |
| **TS + Quadris** | 95.0 a | 77.5 a | 70.8 a | 21.3 a |
| ***Coefficient of Variance (%)*** | **5.8** | **18.2** | **33.9** | **51.6** |

[1] sa=surface area

* means followed by the same letter are not significantly different using an LSD test. ($P$=0.05)

The chemical treatments affected the levels of *Rhizoctonia* on Penta tubers but not on Norland tubers (Table 3.3.3.2). The lowest levels of black scurf on the tubers was found when azoxystrobin (Quadris) was applied in the rows. The average percentage of infected tubers was significantly lower with this treatment than in the mancozeb treated rows. Mancozeb seed treatment (Tuberseal) did not affect the levels of *Rhizoctonia* infection. This is not surprising as this product is registered for control of *Fusarium* seed piece decay only. The higher level of disease in the rows treated with in-furrow mancozeb (Dithane) was unexpected and would be of concern if this effect is consistent. Dithane F45 (37% mancozeb) is registered as a seed treatment of seed potatoes going into storage for control of *Fusarium* dry rot and would be present on seed planted the following spring. Dithane DG Rainshield NT (75% mancozeb) is applied as a foliar fungicide for control of early and late blight. Thus both products could be present during the growing season.

*Rhizoctonia* levels were higher on Norland tubers than on Penta (averages of 56% and 45% infected tubers respectively). Disease levels on the Norland tubers in this trial were also higher than on Norland in an adjacent trail (cultivar effects). These results indicate significant variation in disease levels within the trial area. The high coefficients of

variance also indicate significant variation in levels of inoculum and disease expression in this trial.

**Table 3.3.3.2. Efficacy of fungicide treatments for the control of *Rhizoctonia* – 2003 trial.**

| Fungicide Treatment | Penta | | | Norland | | |
|---|---|---|---|---|---|---|
| | % infected tubers | % tubers >5% sa[1] infected | Av. disease severity | % infected tubers | % tubers >5% sa[1] infected | Av. disease severity |
| **No fungicide** | 48.0 ab* | 18.0 ab | 1.3 ab | 61.5 a | 21.5 a | 1.7 a |
| **Tuberseal (TS)** | 43.0 ab | 12.2 ab | 1.0 ab | 54.0 a | 2.5 a | 0.6 a |
| **TS + Omega** | 48.0 ab | 15.0 ab | 1.4 ab | 61.2 a | 11.5 a | 1.1 a |
| **TS + Dithane** | 58.7 a | 21.2 a | 1.6 a | 49.0 a | 6.7 a | 0.7 a |
| **TS + Quadris** | 29.0 b | 4.2 b | 0.4 b | 53.7 a | 21.2 a | 1.6 a |
| ***Coefficient of Variance (%)*** | ***36.9*** | ***69.1*** | ***56.4*** | ***45.7*** | ***171.0*** | ***122.4*** |

[1] sa=surface area

* means followed by the same letter are not significantly different using an LSD test. ($P$=0.05)

Neither the total nor marketable size yields of either cultivar were affected by any of the chemical treatments. However the level of disease would affect the number of tubers that would be graded-out due to excessive disease. Consequently, marketable yields would be increased by any treatments that decreased disease levels.

**2004 Trial.**

None of the fungicide treatments had any significant impact on levels of either common or powdery scab seen on mature tubers of either test cultivar. Almost 100% of the tubers were affected by common scab. The levels of powdery scab were slightly higher for Penta (average incidence of 58.4%) than for Norland (37.6%). A similar lack of treatments effects was observed in 2003. The incidence and severity of both scab diseases in 2004 was high enough to evaluate the efficacy of the fungicide treatments. By contrast, in 2003 levels of powdery scab were too low to evaluate product efficacy.

The incidence of black scurf in Norland plots was not affected by the fungicidal treatments, but the percentage of Penta tubers with black scurf was significantly reduced when mancozeb (Dithane)or azoxystrobin (Quadris) were applied in furrow (Table 3.3.3.3). The response to in-furrow mancozeb treatment differed in the 2003 and 2004 trials, emphasizing the need for trials to be conducted over a number of years.

The severity of black scurf on cv. Penta was also reduced by these treatments, but not to a significant degree relative to the untreated control (no fungicide applied). In-furrow azoxystrobin also reduced the incidence and severity of black scurf in 2003. This fungicide treatment is registered for control of *Rhizoctonia* stem rot, stolon canker and

**Table 3.3.3.3. Efficacy of fungicide treatments for control of black scurf on Penta tubers – 2004 trial.**

| Fungicide treatment | % infected tubers | % tubers with >5% sa[1] infected |
|---|---|---|
| **No fungicide** | 72.5 a* | 4.5 ab |
| **Mancozeb (TS)** | 62.5 ab | 10.0 a |
| **TS + fluazinam** | 62.5 ab | 3.2 ab |
| **TS + dithane** | 51.0 b | 1.5 b |
| **TS + azoxystrobin** | 47.5 b | 3.2 ab |
| ***Coefficient of Variance (%)*** | ***21.8*** | ***92.3*** |

[1]sa=surface area

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

black scurf, and will be a valuable control product for this disease. Dithane F45 is registered for control of Fusarium dry rot on seed potatoes going into storage. A label expansion to register this product as an in-furrow treatment should be considered if a consistent reduction in black scurf is obtaine din future trials.

The application of the fungicides did not affect the total yields or yields of marketable size tubers. The mancozeb treatment when used alone produced a significant number of tubers with more than 5% surface of their area affected by black scurf. This response would have reduced marketable yield due to grade-out. The reduction in incidence of black scurf by application of dithane and azoxystrobin would increase marketable yield.

Treatment of the seed with mancozeb (Tuberseal) did not reduce disease or increase yields in either 2003 or 2004. Under the management conditions and disease pressures in this trial application of mancozeb to the seed is of questionable value.

**2005 Trial.**

The 2005 growing season was cool and wet during May and June. Precipitation and temperatures were near normal in July and August. Crop establishment was slow but conditions were excellent during tuber set and bulking. 37 cm of rainfall was received over the growing season (normal = 20 cm). A total of 13 cm of supplemental irrigation was applied to the plots. Yields were relatively high in all trials conducted in 2005. No significant problems with diseases or insects were observed in the trial.

Visual examination of the plots showed no effect of the various treatments on emergence, plant growth or vitality. Plant counts were not taken. There were no significant treatment effects on total or marketable size yield (Table 3.3.3.4). The coefficient of variation for the yield parameters was reasonably low.

**Table 3.3.3.4. Total and marketable yield of tubers harvested from chemical control trial – Saskatoon 2005.**

| Treatment (chemical applied) | Average yield of tubers (kg/6m row) | |
|---|---|---|
| | Total weight of tubers | Weight of tubers of marketable size |
| **Allegro** | 40.2 a* | 27.2 a |
| **Tuberseal** | 38.4 a | 27.3 a |
| **Dithane** | 36.4 a | 24.3 a |
| **Ranman** | 37.1 a | 25.2 a |
| **Blinix in-furrow** | 36.0 a | 25.0 a |
| **Blinix at hilling** | 40.8 a | 27.6 a |
| **None (check)** | 39.7 a | 25.7 a |
| ***Coefficient of variance (%)*** | ***10.8*** | ***10.0*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

The incidence of root galls formed by the powdery scab organism was significantly lower in the Ranman treated hills than in the control, Allegro, Tuberseal and Dithane treated hills (Table 3.3.3.5). Blinix treated hills had relatively few galls, but the values were not significantly different from any other treatment. There was no difference between the hills receiving the Blinix at either planting or hilling. The relatively high variance in the root gall data likely reflects non-uniform distribution of powdery scab within both the plot area and the potato root system. The relationship between the incidence and severity of root galls and tuber damage by powdery scab is not clear. However, as root galls represent a significant inoculum source for powdery scab, any treatments that limit root gall formation could help moderate future problems with powdery scab.

**Table 3.3.3.5. Effect of chemical treatments on the incidence of powdery scab galls on potato roots sampled in September 2005.**

| Treatment (chemical applied) | Average gall score |
|---|---|
| **Allegro** | 2.5 a* |
| **Tuberseal** | 2.3 a |
| **Dithane** | 2.4 a |
| **Ranman** | 1.3 b |
| **Blinix in-furrow** | 2.0 ab |
| **Blinix at hilling** | 2.1 ab |
| **None (check)** | 2.6 a |
| ***Coefficient of variance (%)*** | ***29.7*** |

* values followed by the same letter are not significantly different using Duncan's Multiple Range Test, *P*=0.05.

The levels of *Rhizoctonia* on harvested tubers were not affected by the chemical treatments (Table 3.3.3.6). The average incidence of *Rhizoctonia* was not high, with a

range of 18 to 36 % of tubers being infected. The severity of *Rhizoctonia* on the harvested tubers was consistently low. No tubers had more than 5% of the surface area infected by *Rhizoctonia*. The coefficient of variation for the Rhizoctonia data was relatively high – this reflects the infrequent and sporadic occurrence of *Rhizoctonia* in this trial. Application of Ranman significantly reduced the incidence and severity of both powdery and common scab when compared with the levels seen on the untreated check (Table 3.3.3.6). The Ranman treatment appeared particularly effective against powdery scab. The reduction in percentage of tubers with > 5% surface area infected would have reduced losses to grade-out, and thus would have significantly increased the market value of the crop. The coefficient of variation for the common scab ratings was low – this reflects the uniform and high levels of infestation of the site by this pathogen. Although the overall incidence of powdery scab was almost as high as for common scab, the powdery scab is less uniformly distributed across the plot area – resulting in greater variance in the data. More replication and/or larger sample sizes may be required to clarify treatment effects for powdery scab control at this site.

**Table 3.3.3.6. Effect of chemical treatments on disease incidence and severity on tubers harvested in September 2005.**

| Treatment (chemical applied) | % tubers infected with | | | % tubers with > 5% sa[1] infected with | |
|---|---|---|---|---|---|
| | Rhizoctonia | Common scab | Powdery scab | Common scab | Powdery scab |
| **Allegro** | 18.5 a* | 90.5 a | 76.9 ab | 33.3 ab | 25.5 a |
| **Tuberseal** | 35.9 a | 90.8 a | 79.5 ab | 32.4 ab | 33.6 a |
| **Dithane** | 28.4 a | 91.3 a | 83.1 a | 33.9 ab | 23.0 a |
| **Ranman** | 20.0 a | 77.2 b | 30.7 c | 18.3 b | 4.5 b |
| **Blinix in-furrow** | 26.8 a | 89.6 ab | 83.3 a | 36.6 ab | 31.8 a |
| **Blinix at hilling** | 22.0 a | 91.6 a | 68.4 b | 39.1 ab | 18.0 ab |
| **None (check)** | 26.5 a | 93.9 a | 77.1 ab | 54.5 a | 31.0 a |
| ***Coefficient of variance (%)*** | ***44.6*** | ***9.1*** | ***48.4*** | ***9.7*** | ***46.7*** |

[1] sa=surface area

* means followed by the same letter are not significantly different using Duncan's Multiple Range Test, P=0.05.

Application of Blinix at hilling significantly reduced levels of powdery scab and also reduced the severity of the powdery scab problem ($P$=0.09). It should be noted that while Ranman was applied both at planting and hilling, the Blinix treatment was applied either at planting or hilling – but not at both stages. Applying Blinix at both planting and hilling may produce more significant scab control. Further evaluation of both Ranman and Blinix is recommended.

Currently registered seed treatment products, such as Tuberseal, were not effective for control of soil-borne diseases of potatoes. In-furrow applications of azoxystrobin are

presently registered for control of *Rhizoctonia* damage to developing stems. This product also appears to provide a significant degree of protection against black scurf on the harvested tubers that is also caused by *Rhizoctonia*. Application of Ranman (cyazofamid) in-furrow and at-hilling appeared very promising as it provided a reasonable level of control of both common and powdery scab on a moderately scab sensitive variety growing in heavily infested soil. Blinix (Rhamnolipid Biosurfactant) also appears to have some potential – it should be tested at higher rates and/or in multiple applications. It should be emphasized that these results are based on a single site/growing season – more research is required.

### 3.3.4. Effect of green manure crops on soil-borne diseases of potato

Green manuring is a well-established method for maintaining soil health and fertility. Interest in using green manures to minimize disease levels has increased in the past few years. Incorporation of a green manure crop before planting a potato crop may alter the soil chemistry or microflora, which in turn may reduce the number and/or infectivity of soil-borne pathogenic organisms. Green manuring represents an acceptable method of disease control for organic and low input producers.

The impact of green manures on soil health and disease suppression depends on the plant species used as the manure crop, the amount and timing of green manuring, the host crop and the disease pressure in the field. Ideally green manure crops are planted so that they produce a large plant biomass that is incorporated just prior to seeding of the target crop. In the potato producing areas of the United States, green manure crops are planted in the fall – they grow slowly over the winter months and are disced under just prior to planting the potato crop. In regions where fall cropping is not possible, the green manure crop is grown in the season prior to cropping to potatoes.

The potential to use green manure to manage powdery scab and common scab is not well documented. The objective of this trial was to evaluate the impact of several green manure crops on yield and disease development of potato under Saskatchewan growing conditions.

**Materials and Methods:**

In spring 2003, trial plots were seeded to the following green manure treatments;

1) *Sinapis alba* (cultivar Pennant),
2) *Brassica juncea* (cultivar Vulcan),
3) *B. napus* (canola, cultivar Kelsey)
4) *Lolium multiflorum* (annual ryegrass)

The three cruciferous and one ryegrass crop were selected for this trial as research by R. Larkin and T. Griffin, University of Maine indicates that these species are effective in reducing the levels of scab and *Rhizoctonia* infection (R. Larkin, personal

communication). Cruciferous crops contain glucosinolates that are released into the soil when the crop breaks down, and these compounds may control populations of soil microbes.

Each green manure treatment was planted in 8X8 m areas in a randomized block design with four replications. The seed of the green manure crops was broadcast at double the normal seeding rate on April 24 and allowed to grow until June 6, when seed potatoes were planted directly into the green manure crop. Evaluation of the weights of the different types of plants growing in randomly selected $0.5m^2$ areas of each plot were made a few days before potato planting. Two 6m rows of Penta and two 6m rows of Norland were planted into each treatment area. Guard rows were planted on the outside of each area and between the two cultivars. Green manure material was either turned under during the planting process (Figure 3.3.4.1) or during subsequent hilling operations. The crop was grown under standard management practices, and irrigated as necessary. Plots were top-killed and tubers were harvested the third week of September.

**Results and Discussion:**

The amount of green material produced in a randomly chosen 0.5 $m^2$ was measured in each replicate plot before the potato seed was planted. The fresh weight of the green material varied between crops, with *L. multiflorum* plots producing the most total plant material, and *B. juncea* the least (Table 3.3.4.1). *Sinapis alba* produced a reasonable canopy but the other two cruciferous crops did not establish an adequate crop. Grassy weeds, mainly barnyard grass and green foxtail, occurred in all plots, with the lowest levels in the *B. juncea* plots. The dicotyledonous weeds that were present were redroot pigweed, wild buckwheat, round-leaved mallow, Russian thistle, lamb's quarters, dandelion and wild tomato. Variation in the kind of plant material produced depended on the vigour of the seed planted and competition between the species. The variation in density of green manure plants would increase the variation in disease response. The stands obtained for the green manure plots were not typical of a healthy crop, with the exception of the *S. alba* plots, where a significant number of cruciferous plants did become established (Figure 3.3.4.2).

**Table 3.3.4.1. Yield of above-ground plant material produced by several spring-seeded green manure crops prior to planting with potatoes – 2003 trial.**

| Green Manure Treatment | Average weight of above-ground plant material (g per 0.5 $m^2$, n=4) | | | |
|---|---|---|---|---|
| | Monocotyledonous plants | Cruciferous plants | Other dicotyledonous plants | Total plant weight |
| Stubble | 264.6 | 0.0 | 27.3 | 291.9 |
| *B. juncea* | 144.8 | 119.6 | 15.5 | 279.9 |
| *S. alba* | 165.9 | 293.6 | 9.5 | 469.0 |
| *B. napus* | 314.3 | 30.8 | 33.7 | 378.8 |
| *L. multiflorum* | 309.7 | 8.1 | 49.0 | 745.6 |

Penta tubers harvested from plots green manured with *Sinapis alba* developed significantly more powdery scab, based on the numbers of tubers with >5% surface area affected (Table 3.3.4.2). However, variability was extremely high and levels of disease wer elow, so this response may not be found consistently. The levels of common scab and *Rhizoctonia* on Penta tubers were not affected by any of the green manure treatments. The levels of *Rhizoctonia*, common and powdery scab on the Norland tubers were not affected by any of the green manure treatments.

The total and marketable size yields of Norland tubers were significantly increased in plots where *S. alba* and ryegrass had been incorporated, compared with the barley stubble and *B. juncea* plots (Table 3.3.4.3). There is no obvious explanation for this increase in

**Table 3.3.4.2. The impact of green manure crops on development of powdery scab on Penta and Norland tubers – 2003 trial.**

| Green Manure Treatment | Penta | | Norland | |
|---|---|---|---|---|
| | % tubers infected : | % tubers with >5% sa[1] infected | % tubers infected : | % tubers with >5% sa[1] infected |
| Stubble | 1.6 a* | 0.0 b | 8.7 a | 7.9 a |
| *B. juncea* | 2.0 a | 0.0 b | 5.0 a | 3.7 a |
| *S. alba* | 7.9 a | 2.4 a | 0.0 a | 0.0 a |
| *B. napus* | 2.7 a | 0.0 b | 2.5 a | 2.5 a |
| *L. multiflorum* | 0.9 a | 0.4 b | 0.0 a | 0.0 a |
| *Coefficient of Variance (%)* | *195.6* | *224.1* | *198.7* | *205.8* |

[1] sa=surface area

* means followed by the same letter are not significantly different using an LSD test. (P=0.05)

**Table 3.3.4.3. The impact of green manure crops on total and marketable size yield of Penta and Norland tubers – 2003 trial.**

| Green Manure Treatment | Penta | | Norland | |
|---|---|---|---|---|
| | Total yield (kg/6m row) | Marketable size yield (kg/6m row) | Total yield (kg/6m row) | Marketable size yield (kg/6m row) |
| *Stubble* | 21.5 a* | 14.1 a | 23.2 b | 20.9 b |
| *B. juncea* | 22.3 a | 18.1 a | 22.5 b | 19.8 b |
| *S. alba* | 22.7 a | 18.4 a | 27.4 a | 24.6 a |
| *B. napus* | 21.4 a | 17.4 a | 25.7 ab | 23.0 ab |
| *L. multiflorum* | 22.0 a | 16.9 a | 27.7 a | 25.0 a |
| *Coefficient of Variance (%)* | *10.7* | *23.7* | *10.6* | *9.3* |

* means followed by the same letter are not significantly different using an LSD test. (P=0.05)

yield and repetition of the trial is necessary to evaluate the consistency of this response. Yields of Penta were not affected by the green manure treatments.

Being able to seed the green manure crop either in the fall or in the spring prior to the potato crop would represent a convenient and cost effective method of green-manuring, providing that it was also effective. Due to problems with stand establishment and the short period of time between seeding of the green manure crops and establishment of the potato crop, relatively little biomass of the green manure crops was produced in the 2003 trial. This may be reflected in the minimal degree of disease control observed in this study. It is unlikely that green manuring in the same season as planting potatoes will be effective in a typical Saskatchewan season.

**2004/2005 Trial.**

In July 2003, plots were seeded with the same green manure crops in an attempt to establish a good cover crop for use as green manure in 2004. However, the seedlings of the green manure crops were lost to insects (flea beetles and grasshoppers). The green manure plots were seeded again in November, with the hope that the fall-seeding would allow for early germination and establishment of the green manure crops. This would allow the potato crop to be planted into a current season green manure crop.

The ryegrass green manure plots established well and grew vigorously, but the cruciferous crops were weedy and the stand was poor. The green manure stand was too sparse to justify planting a potato crop into them in 2004. Instead, on June 25$^{th}$ , all the plots except for the ryegrass plots were knocked down with a weed-whacker. The plots were cultivated twice on June 29$^{th}$ and reseeded with the same green manure species on June 30$^{th}$. Furadan was applied with the seed to minimize flea beetle damage. The plots were harrowed immediately after planting and also irrigated to assist establishment.

The cruciferous plots were flowering by August 5$^{th}$. The ryegrass plots had headed the previous month. All plots had dense stands of the manure crops (Figure 3.3.4.3). The control plots were cultivated to kill any weeds.

On August 16$^{th}$, 20 plants selected from four randomly chosen locations within each green manure plot was harvested and their roots examined for the presence of *Spongospora subterranea* galls. No sign of infection by this pathogen was found. This sampling was carried out because in 2004 Qu and Christ reported that Yellow mustard (*Brassica campestris*) became infected with powdery scab and produced spore balls in galls on the roots (Qu & Christ. The host range of *Spongospora subterranea* f. sp. *subterranea* in the United States. Presented in a poster at the Annual Meeting of the Potato Association of America, Scottsbluff, Nebraska).

On August 17$^{th}$, the above-ground plant matter in randomly chosen 0.5 m$^2$ areas were harvested and their fresh weights determined. An average of 8.2 kg, 5.6 kg, 6.4 kg and 7.6 kg/ m$^2$ of fresh weight was recorded for *B. juncea*, *S alba*, *B. napus* and *L.*

*multiflorum* respectively. The plots were flail-mowed on 18th August and the plant material was immediately incorporated with a rotavator.

The 2005 trial was planted into the green manure plots that had been established and then ploughed under in 2004. Standard site preparation methods were employed. The trial was planted in mid-May using cv Norland and Penta seed obtained from local certified seed growers. The plots were planted with 25 cm between seedpieces within a row and 1 m between rows, with each treatment row being 6 m long. Two rows of each cultivar were planted in each plot – one row was used for in-season disease evaluations, while the other row was used for yield and tuber quality assessments. The trial was laid out in a split plot design with green manures as the main plot and cultivars as the sub-plots. Each treatment combination was replicated five times.

Standard crop management practices were employed. An overhead irrigation system was utilized to maintain soil moisture levels. Weeds were control using tillage and herbicides. No significant problems with diseases or insect pests were observed. The plots were chemically desiccated in early September and were harvested by late September. Yields and the incidence of disease on the harvested tubers were evaluated utilizing previously described methods.

**Results and Discussion:**

Crop vigor was good in this trial – with no effects of the green manure treatments on stand or vegetative vigor being observed.

Root galls were more common on Norland than on Penta roots. None of the green manure treatments had any impact on root gall production by either cultivar (Table 3.3.4.4).

**Table 3.3.4.4. Impact of green manures on powdery scab root gall ratings for Norland and Penta potatoes – 2005 trial.**

| | B. juncea | S. alba | B. napus | L. multiflorum | Stubble | LSD (0.10) | CV (%) |
|---|---|---|---|---|---|---|---|
| **Norland** | 2.3 | 2.1 | 2.2 | 2.3 | 1.7 | **NS** | **42** |
| **Penta** | 0.4 | 0.9 | 0.2 | 0.2 | 0.1 | **NS** | **111** |
| **Mean** | **1.4** | **1.5** | **1.2** | **1.2** | **0.9** | | |

Black scurf was more prevalent on Norland than on Penta (Table 3.3.4.5). In both cultivars, the B. napus green manure appeared to suppress *Rhizoctonia* relative to some of the other green manure treatments and the stubble control.

**Table 3.3.4.5. Impact of green manures on Rhizoctonia (black scurf) ratings for Norland and Penta potatoes – 2005 trial.**

| | B. juncea | S. alba | B. napus | L. multiflorum | Stubble | LSD (0.10) | CV (%) |
|---|---|---|---|---|---|---|---|
| **Norland** | 42 | 50 | 28 | 51 | 46 | **20** | **26** |
| **Penta** | 3 | 6 | 2 | 3 | 13 | **6** | **88** |
| **Mean** | **22** | **28** | **15** | **26** | **29** | | |

Levels and severity of common scab were high in this trial, with Penta more severely damaged than Norland. None of the green manure treatments had any impact on either the incidence or severity of common scab on either cultivar (Table 3.3.4.6).

**Table 3.3.4.6. Impact of green manures on % of tubers of Norland and Penta with common scab and the common scab severity ratings – 2005 trial.**

| | *B. juncea* | *S. alba* | *B. napus* | *L. multiflorum* | Stubble | LSD (0.10) | CV (%) |
|---|---|---|---|---|---|---|---|
| | | | **% tubers with Common Scab** | | | | |
| **Norland** | 81 | 85 | 88 | 83 | 82 | **NS** | **13** |
| **Penta** | 99 | 99 | 96 | 92 | 98 | **NS** | **6** |
| **Mean** | **90** | **92** | **92** | **88** | **90** | | |
| | | | **% tubers with severe Common Scab** | | | | |
| **Norland** | 25 | 26 | 26 | 25 | 24 | **NS** | **44** |
| **Penta** | 61 | 60 | 62 | 55 | 58 | **NS** | **16** |
| **Mean** | **43** | **43** | **44** | **40** | **41** | | |

Levels and severity of powdery scab were moderately high in this trial, with Penta having less severely infected tubers than Norland. In Penta, the rye-grass reduced the incidence of severe powdery scab relative to the *Brassica juncea* treatment (Table 3.3.4.7).

Yields of both cultivars were relatively high in this trial. For Norland, the average yield of marketable sized tubers obtained when ryegrass green manure was used was higher than when the crop was planted into areas where the field had been in fallow the previous season (Table 3.3.4.8).

**Table 3.3.4.7. Impact of green manures on % of tubers of Norland and Penta with powdery scab and the powdery scab severity ratings – 2005 trial.**

| | *B. juncea* | *S. alba* | *B. napus* | *L. multiflorum* | Stubble | LSD (0.10) | CV (%) |
|---|---|---|---|---|---|---|---|
| | | | | % tubers with Powdery Scab | | | |
| **Norland** | 65 | 62 | 45 | 38 | 40 | NS | 32 |
| **Penta** | 62 | 64 | 48 | 46 | 58 | NS | 29 |
| **Mean** | **63** | **63** | **46** | **42** | **49** | | |
| | | | | % tubers with severe Powdery Scab | | | |
| **Norland** | 26 | 19 | 13 | 16 | 9 | NS | 77 |
| **Penta** | 6 | 6 | 8 | 0 | 4 | 6 | 122 |
| **Mean** | **16** | **12** | **10** | **8** | **7** | | |

**Table 3.3.4.8. Impact of green manures on yields for Norland and Penta potatoes – 2005 trial.**

| | *B. juncea* | *S. alba* | *B. napus* | *L. multiflorum* | Stubble | LSD (0.10) | CV (%) |
|---|---|---|---|---|---|---|---|
| | | | | Total yields (t/ha) | | | |
| **Norland** | 65.4 | 61.8 | 64.0 | 60.0 | 56.5 | NS | 14 |
| **Penta** | 60.0 | 63.5 | 62.1 | 67.7 | 51.3 | NS | 26 |
| **Mean** | **62.7** | **62.5** | **63.0** | **63.9** | **53.9** | | |
| | | | | Marketable size yields (t/ha) | | | |
| **Norland** | 43.0 | 44.0 | 45.2 | 48.8 | 39.5 | 8.8 | 15 |
| **Penta** | 46.3 | 48.0 | 50.7 | 54.3 | 40.3 | NS | 25 |
| **Mean** | **44.7** | **46.0** | **48.0** | **51.6** | **39.9** | | |

### 3.3.5. Efficacy of green manures for control of seed-borne disease of potato

#### A. Growth Cabinet Study No. 1

Growth cabinet studies allow for control of many of the factors that influence disease and crop growth. In studies of disease management of potato, use of growth cabinets allows the control of temperature, soil moisture condition, inoculum level. In field trials designed to evaluate the impact of green manure crops on soil-borne diseases of potato, the trials had been compromised initially by difficulties in establishing the green manure crops.

Growth cabinet studies were therefore designed to evaluate the effect of green manure on disease development associated with **seed infected** with black scurf and both scabs.

The green manure crops used in this pot experiment were the same as those used in the field trial; 1) *S. alba*, 2) *B. juncea*, 3) *B. napus*, 4) *L. multiflorum*, 5) no amendment. ( See section 3.3.4). The green manure crops were seeded thickly in flats and grown to flowering (approximately six weeks). The plant material (above and below ground) was cut into approximately 2 cm lengths (Figure 3.3.5.1), and incorporated into potting media (Sunshine mix 4, Aggregate plus) (Figure 3.3.5.2). Approximately 15 g of the selected green manure species was present in each one-gallon pot. This high rate of incorporation, as shown in Figure 3.3.5.2, was chosen to maximize the potential benefit of using the green manure. It may not be possible to obtain such a high rate of green manuring in the field.

Seed potatoes of the cultivar Penta, produced in 2003 field trials in the Horticulture plots University of Saskatchewan, were examined for levels of *Rhizoctonia* and scab infection. The tubers were separated into four categories: 1) clean with no visible signs of disease, 2) *Rhizoctonia* infection on at least 1% of the surface area, 3) at least 1% of the surface area infected with common scab, 4) powdery scab lesions with cystosori present. Forty seed pieces of each disease category were cut and allowed to dry for 48 hours, before planting one tuber per pot. Eight pots of each green manure/seed treatment were placed in a growth chamber with a 14 hour day, day temperature of 20°C, and night temperature of 16°C. After four weeks, when the plants began initiating tubers, half the pots were placed in a chamber with 28°C day and 22°C night for the next four weeks (regime 1) while the other pots continued at the original settings (regime 2). The hotter, drier conditions of regime 1 were conducive to the development of common scab, while regime 2 was more conducive to powdery scab. Pots were all watered with the same amount of water, but the pots at the higher temperatures dried out more between watering. After four weeks all pots were returned to the original conditions. The pots were randomized within the regimes, except for the pots containing the powdery scab infected seed which were kept apart as this disease appears to be spread when water splashes from pot to pot (personal experience). Fertilizer (20:20:20) was applied weekly during watering for the last four weeks of the experiment.

The tubers were harvested after ten weeks and disease development on the roots and tubers was determined. *Rhizoctonia* lesions on the stems and tubers, scab symptoms on the tubers and the numbers of galls formed on the roots were recorded. *Rhizoctonia* lesions and the gall scores were rated using the scoring system described in section 3.2.2. Infection of tubers by both scabs was recorded as the average surface area infected for the tubers formed in each pot. This data was transformed using log (x + 0.1) before analysis, to compensate for the non-normal data distribution; the data presented in the tables is non-transformed. The results from the two temperature regimes were analysed separately.

**Results and Discussion:**

No galls were formed on any plants grown under regime 1, indicating that the hotter, drier conditions were not conducive to infection of roots by *S. subterranea*. Plants grown under regime 2 developed a few powdery scab galls on their roots. There were no significant effects of the green manure treatments on gall production. Although gall numbers were low, significantly more galls were formed on plants produced from powdery scab infected seed than from clean seed (Table 3.3.5.1). The common scab and black scurf infected seed had no visible symptoms of powdery scab. Nonetheless, a few powdery scab galls were formed on the roots of plants grown from this seed. This emphasizes the problem of using visual inspection to ensure that tubers are disease free.

**Table 3.3.5.1. Impact of tuber infection on subsequent infection of roots by powdery scab, under regime 2 conditions.**

| Seed infected with: | Mean number of galls per root |
|---|---|
| **No visible pathogen** | 0.00 b* |
| **Common scab** | 0.03 b |
| **Black scurf** | 0.08 ab |
| **Powdery scab** | 0.14 a |
| ***Coefficient of Variance (%)*** | ***259.6*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

There was insufficient disease to evaluate the effect of green manure treatment on powdery scab levels on the tubers as powdery scab lesions only formed on two tubers, produced from infected seed, grown under regime 2. Powdery scab infected seed was not a good source of disease inoculum under the growth room conditions used in this experiment.

Black scurf levels on the harvested tubers were low under both regimes. There was no significant effect of type of seed on subsequent levels of black scurf under regime 1. However, under regime 2, where soil temperatures were lower and soil moisture levels maintained more evenly, planting clean seed produced more *Rhizoctonia* stem/root infection than planting seed with visible common scab lesions (Table 3.3.5.2).

Green manure treatments did not influence damage of the shoots and roots by *Rhizoctonia* under the drier conditions of regime 2. Under the cooler wetter conditions of regime 1, significantly more *Rhizoctonia* damage occurred on plants grown in ryegrass-amended soil compared with *B. juncea*-amended soil (Table 3.3.5.3). However none of the green manure treatments differed significantly from the non-amended treatment.

**Table 3.3.5.2. Impact of tuber infection on infection of shoots/roots by *Rhizoctonia*, under regime 2 conditions.**

| Seed infected with: | Average root/shoot score |
|---|---|
| **No visible pathogen** | 0.37 a* |
| **Powdery scab** | 0.25 ab |
| **Black scurf** | 0.13 ab |
| **Common scab** | 0.00 b |
| ***Coefficient of Variance (%)*** | ***244.1*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

**Table 3.3.5.3. Impact of green manure treatment on infection of shoots/roots by *Rhizoctonia* under regime 2 conditions.**

| Green manure incorporated: | Average root/shoot score |
|---|---|
| **None** | 0.25 ab* |
| ***S. alba*** | 0.35 ab |
| ***B. juncea*** | 0.07 b |
| ***B. napus*** | 0.27 ab |
| ***L. multiflorum*** | 0.66 a |
| ***Coefficient of Variance (%)*** | ***209.0*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

Plants grown under the hotter, drier conditions of regime 1 produced more tubers infected with common scab than under the cooler, moister conditions of regime 2. Significantly more common scab infected tubers were also produced from seed infected with the pathogen (Table 3.3.5.4) than from any of the other seed sources.

**Table 3.3.5.4. Impact of tuber infection on infection of daughter tubers by common scab under regime 1 conditions.**

| Seed infected with: | Average % surface area infected |
|---|---|
| **No visible pathogen** | 0.0 b* |
| **Common scab** | 2.96 a |
| **Powdery scab** | 0.09 b |
| ***Rhizoctonia*** | 0.13 b |
| ***Coefficient of Variance (%)*** | ***645.9*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

None of the green manure treatments reduced the incidence of common scab. The severity of common scab was significantly greater on plants produced in pots with soil amended with *B. napus* (canola) than in soil with no amendments (Table 3.3.5.5). As

canola is frequently grown in rotation with potatoes this could have serious implications for growers.

**Table 3.3.5.5. Impact of green manure treatment on infection of tubers by common scab under regime 1 conditions.**

| Green manure incorporated: | Average % surface area infected |
|---|---|
| **None** | 0.03 b* |
| ***S. alba*** | 0.10 b |
| ***B. juncea*** | 0.19 b |
| ***B. napus*** | 1.6 a |
| ***L. multiflorum*** | 0.20 ab |
| ***Coefficient of Variance (%)*** | ***645.9*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

The levels of the three diseases developed in this experiment were low and did not adequately test the effectiveness of the green manure treatments. The coefficients of variance were very high in all the pot experiments, indicating extreme variability in the results. Infected seed does not appear to be a suitable source of disease inoculum under these conditions and further experiments are needed to confirm these results. The use of Sunshine mix, which is high in peat content, may also have affected the results. A mixture using soil, sand and perlite in a 1:1:1 ratio would be more suitable and will be used in subsequent experiments.

**Efficacy of green manure amendments for control of soil-borne potato disease**

**B. Growth Cabinet Study No.2**

The disease inoculum needed for infection of potatoes by scab and *Rhizoctonia* is either introduced into the field on seed or is already present in the soil. The previous experiment indicated that seed-borne inoculum did not produce significant amounts of scab or *Rhizoctonia* under growth cabinet conditions

The objective of this experiment was to evaluate the effect of green manure on disease development from inoculum of *R. solani*, *S. scabies* and *S. subterranea* **present in soil**.

Green manure crops were grown and incorporated into the soil mixture as previously described. Healthy, disease-free seed tubers (cv. Penta) were cut into 2 oz pieces and suberized at room temperature for two days before planting in one-gallon pots.

The green manure treatments were the same as those used in the previous experiment. The soils used were:

1. potting soil (Sunshine Mix #4, aggregate plus) – pathogen free control.
2. soil collected from a field infested with *S. scabies*
3. soil collected from a field infested with *S. subterranea*
4. soil collected from University plots, infested with both scab organisms and *Rhizoctonia*.

The presence of pathogens in these soils was deduced from the fact that potatoes produced in these fields in previous years had been infected with the specified pathogens. Soils #2 and #3 were sandy, and #4 was a sandy loam. The soils were mixed 1:1 with Sunshine Mix #4.

Five pots of each green manure/soil combination were planted and then placed in a growth room with 14 hour day, 20°C day and 16°C night. Equal quantities of each soil plus the green manure treatment were stored in plastic containers for four weeks at 20°C, to allow for breakdown of the green manure material. The soil + green manure was stirred once during this period. Some mould growth was noted on the soil surface in some containers. The second set of five replicate pots were planted after four weeks and placed under the same conditions as the first planting. The plants were maintained as previously described. After 12 weeks of growth the tubers were harvested from the pots and examined for disease.

**Results and Discussion:**

The amount of time between incorporation of the green manure and planting of the potato seed tubers had no effect on development of either scab disease. However, the level of *Rhizoctonia* was lower when tubers were planted directly into the green manures soil mixture compared to when the soil + green manure mixture was stored for a month before planting (Table 3.3.5.6). This implies that the anti-fungal activity of the green manure is more effective immediately after incorporation of the manure.

**Table 3.3.5.6. Influence of length of time after incorporation of plant material on development of *Rhizoctonia*.**

| Incorporation of green manure: | *Rhizoctonia* infection – average disease score of shoot/root |
|---|---|
| **immediately before planting** | 0.56 b* |
| **4 weeks before planting** | 0.94 a |
| ***Coefficient of Variance (%)*** | ***145.9*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

Common scab was found on only one tuber, regardless of soil type or green manure treatment, and there were no significant differences in the levels of black scurf infection on tubers grown in soils with different types of inoculum. However plants grown in soils infested with common scab and powdery scab inoculum developed significantly higher levels of both *Rhizoctonia* on the roots and powdery scab on tubers and roots than plants grown in potting soil and the soil infested with both scab organisms (Table 3.3.5.7).

Higher levels of disease were observed on the tubers and roots when inoculum was introduced using infested soil as compared to infested seed (see Growth Cabinet Study

No.1). However the levels of the various diseases were still very low relative to the levels observed under field conditions. This suggests that the conditions used in this trial were not conducive to disease development.

**Table 3.3.5.7. Influence of soil inoculum type on the development of *Rhizoctonia* and powdery scab infection.**

| Soil inoculum type | Disease development | | |
|---|---|---|---|
| | Average *Rhizoctonia* score on root/shoot | Average powdery scab gall score | Average % surface area of tuber infected with powdery scab |
| **Potting soil** | 0.48 b* | 0.04 c | 0.01 b |
| **Infested with common scab** | 1.25 a | 1.73 b | 3.42 a |
| **Infested with powdery scab** | 1.00 a | 2.05 a | 2.70 a |
| **Infested with both scabs** | 0.29 b | 0.08 c | 0.07 b |
| ***Coefficient of Variance (%)*** | ***145.9*** | ***67.1*** | ***122.4*** |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

The greatest gall production by powdery scab occurred in the soil heavily infested with powdery scab (Table 3.3.5.7). Very few galls occurred on plants grown in potting soil or the media infested with both scab organisms. Higher levels of powdery scab infection were seen on tubers grown in the two scab infested soils compared with the other two soils. Low levels of pathogen in the pure potting soil are not surprising as this should be a pathogen-free medium. The low level of pathogen inoculum in soil infested with both scabs is surprising as this soil was collected from an area where tubers heavily infected with both organisms were produced in the previous year. Common and powdery scab and *Rhizoctonia* are frequently found in the same soils. Disease expression in any one year is mainly due to the prevailing soil conditions that may be more favourable to any one pathogen. The lack of common scab development (infection was found on a single tuber) was likely due to the growth room conditions. The pots were kept relatively damp and the temperatures were relatively cool (average 18°C). These conditions are more conducive to infection by *S. subterranea* and *Rhizoctonia* than *S. scabies*.

Incorporation of green manure had no effect on powdery scab gall development on the roots or on black scurf levels on tubers. However, ryegrass incorporation significantly reduced *Rhizoctonia* infection of root/shoot, when compared with untreated soil (Table 3.3.5.8). The addition of *B. juncea* as a green manure significantly reduced powdery scab infection of the tubers. The differences between the other green manure treatments were not significant, but all green manure treatments appeared to reduce disease levels to some degree relative to the controls. This result confirms the need for adequate field-testing of these manures, in particular the addition of *B. juncea* and/or *L. multiflorum*.

**Table 3.3.5.8. Effect of green manure incorporation on *Rhizoctonia* and powdery scab infection.**

| Green manure incorporated: | Disease development | |
|---|---|---|
| | Average *Rhizoctonia* score on root/shoot | Average % surface area of tuber infected with powdery scab |
| None | 1.11 a* | 2.07 a |
| *S. alba* | 0.83 ab | 1.50 ab |
| *B. juncea* | 0.79 ab | 1.12 b |
| *B. napus* | 0.60 ab | 1.65 ab |
| *L. multiflorum* | 0.44 b | 1.20 ab |
| *Coefficient of Variance (%)* | *145.9* | *122.4* |

* means followed by the same letter are not significantly different (P=0.05), using the Duncan's Multiple Range test.

### 3.3.6. Mustard meal amendments for control of soil-borne diseases of potato

#### Introduction

Previous research suggests that the glucosinolates present in the tissues of members of the *Brassicacea* have the potential to suppress the development of a range of plant pathogens. These glucosinolates are thought to present the basis for the disease suppression seen when *Brassica* crops are included in crop rotations. The amount of glucosinolate produced by the green manure crops varies with the type of plant being grown, its growth stage and the length of time between when the green manure crop was ploughed down and when the next crop was planted.

Granular mustard meals, produced from deoiled seed by Peacock Industries, Hague, are being tested for control of nematodes, and possibly other pests, by Mikio Chiba of Nematrol Inc, Ontario. The meal is a by-product of the process used to manufacture bio-fuel. The meal contains high levels of glucosinolates and other potentially bio-active compounds and as such it may be useful in pest control. Meal products from a range of different *Brassica* species are available. These products vary in their glucosinolate content.

The objective of this experiment was to evaluate the ability of meals produced from different cruciferous species to act as disease control agents under controlled and field conditions. The impact of timing of application of the meal and meal formulation were also evaluated.

## A. Growth Cabinet Studies

### Materials and Methods:

Six kinds of meal were evaluated for control of soil-borne pathogens. The meals were added to disease-infested soil in one-gallon pots. The soil sources were described in detail in the previous experiment (section 3.3.5).

These soils were mixed in the ratio of:
1 part soil infested with common scab:1 part soil infested with powdery scab:1 part soil infested with both scab pathogens:12 parts "Sunshine Mix #4 Aggregate Plus".

The meals were mixed in with the soil at the rate of 6g /one-gallon pot (equivalent to the rate of 60lbs/1000sq ft recommended by M. Chiba).
The meals used were derived from the following crops:

1. *Sinapis alba*
2. *Brassica juncea* (cultivar Arid, low glucosinolate type)
3. *B. juncea* (cultivar Cutlass, high glucosinolate type, batch #18, includes additives)
4. *B. carinata*
5. *Camelina sativa*
6. *B. juncea* (high glucosinolate, batch #4, no additives)

Enough soil/meal combination was mixed into 15 one-gallon pots. Five of the pots were planted immediately with healthy, whole Norland seed tubers. The remainder of the pots were stored in plastic boxes at 20°C. A second set of five pots was planted after one week of storage and the final set of pots was planted three weeks after incorporation of the various types of meal. The soil was kept moist during mixing to reduce dust levels. Pots were watered immediately after planting and were placed in a growth room with a 14 hour day at 20°C in the day and 16°C at night. Fertilizer (20:20:20) was applied weekly during watering for the last four weeks of the experiment.

Each set of plants was harvested 12 weeks after planting and roots/shoots and tubers were examined for disease as previously described.

### Results and Discussion:

More powdery scab galls formed on the roots of plants grown in freshly incorporated meal, compared with planting after one and three weeks after incorporation of the meal (Table 3.3.6.1). This is in contrast to the previous experiment where reduction in *Rhizoctonia* occurred when tubers were planted immediately after green manure was added. Gall formation by the powdery scab organism occurs when motile spores of the pathogen invade the roots. It appears that less infection of roots occurs when meal is incorporated into soil from one to three weeks before the roots begin to grow in the soil. Possibly this extra time allows for destruction of the pathogen, thus reducing the inoculum available for root infection. There was no difference in gall score between

waiting one or three weeks before planting. There were no signs that plants suffered from the presence of fresh meal, but yield data were not collected in this trial.

**Table 3.3.6.1. Effect of timing of incorporation of meal on powdery scab gall score.**

| Time between incorporation and planting | Gall score |
|---|---|
| None | 3.74 a* |
| 1 week | 1.03 b |
| 3 weeks | 1.83 b |
| *Coefficient of Variance (%)* | *160.4* |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

There were no significant differences in the number of powdery scab galls formed in pots containing the various different types of meal. The lowest gall score was obtained in soil with no meal added, while the highest score was found in the pots with *Camelina sativa* added (Table 3.3.6.2). This result suggests that meal incorporation was not effective in reducing the number of powdery scab galls formed, and *C. sativa* may actually have increased gall production. The time of planting after mustard meal incorporation did not affect the level of powdery scab on the tubers.

The type of meal did affect the percentage of tuber surface that was infected with powdery scab. *B.carinata* and *B.juncea* (batch 4) meal significantly reduced levels of powdery scab in comparison with the non-amended soil or the soils amended with *S. alba* and *C. sativa* (Table 3.3.6.2; analysis performed on transformed data, non-transformed data reported in table). Addition of meal to the soil appears to influence gall formation and tuber scab in different ways. These experiments should be repeated to verify that the results are consistent.

**Table 3.3.6.2. Effect of type of meal incorporated on powdery scab gall formation and tuber infection by powdery scab.**

| Type of meal incorporated: | Average gall score | % tuber surface infected |
|---|---|---|
| *S.alba* | 2.4 ab* | 17.03 a |
| *B. juncea* low gc[a] | 1.4 ab | 13.95 ab |
| *B. juncea* high gc, batch 18 | 2.3 ab | 15.73 ab |
| *B. carinata* | 2.0 ab | 13.62 bc |
| *C. sativa* | 3.6 a | 15.62 ab |
| *B. juncea* high gc, batch 4 | 2.7 ab | 8.35 c |
| No meal added | 1.0 b | 26.12 a |
| *Coefficient of Variance (%)* | | *160.4* |

[a] gc=glucosinolate

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

The severity of black scurf on tubers was very low in all treatments. Neither *Rhizoctonia* infections of tubers, nor of root/shoot were affected by the time of planting after incorporation or the type of meal used. Rhizoctonia levels on plants grown in the different meals did not differ significantly from the control. However plants in *B. juncea* (batch 4) treated pots had significantly more *Rhizoctonia* root infection than plants in

**Table 3.3.6.3. Effect of type of meal incorporated on *Rhizoctonia* infection of root/shoot.**

| Type of meal incorporated: | Average Rhizoctonia score |
|---|---|
| ***S.alba*** | 1.77 ab* |
| ***B. juncea* low gc**[a] | 2.65 ab |
| ***B. juncea* high gc, batch 18** | 1.15 b |
| ***B. carinata*** | 2.53 ab |
| ***C. sativa*** | 1.21 ab |
| ***B. juncea* high gc, batch 4** | 2.94 a |
| **No meal added** | 1.65 ab |
| ***Coefficient of Variance (%)*** | ***121.9*** |

[a] gc=glucosinolate

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

batch 18 treated pots (Table 3.3.6.3). This suggests that variation in meal preparation may impact the effect of the product on disease levels. Batch 4 meal was the same as batch 18 except that there were no additives (proprietary information). Again, this experiment needs repeating to verify consistency of results.

## B. 2004 field trials

The mustard meals evaluated in the previous growth chamber experiments were also assessed in two field trials. In the first trial six types of mustard meal produced from four different crop species were tested as disease control agents. The objective of this trial was to determine if incorporation of these meals at planting had any effect on crop yields and disease development for potatoes. In the second trial the effect of timing and amount of mustard meal on yield and disease development was examined.

### Materials and Methods:

**Trial 1** - Six types of mustard meal were applied on the surface of rows before planting, so that the meal became incorporated into the hill during planting with a mechanical planter. The meal was applied at a rate of 0.7kg/8m row except for treatment six, which was applied at 1kg/row. This increased rate corrects for the fact that the level of the active ingredient in this meal was found to be lower than expected when analysed by M. Chiba. All rates were as recommended by M.Chiba.

The meals used were derived from:

1. *Sinapis alba*
2. *Brassica juncea* (low glucosinolate)
3. *Camelina sativa*
4. *B. carinata*
5. *B. juncea* (high glucosinolate, batch 4)
6. *B. juncea* (high glucosinolate + additives, batch 18)
7. No meal

The trial was conducted at the previously described scab nursery site, following standard production practices. The plots were seeded on June 9th 2004 using certified Norland seed. Tubers were planted 25cm apart, in 8m rows, 1m apart, using a randomized block design with 4 replicates. The crop was overhead irrigated whenever soil water potentials fell below –60 kPa. No significant problems with insect or foliar diseases were observed. The crop was chemically dessicated in early September and harvested in late September. The crop was stored, graded and evaluated for disease as described previously.

**Trial 2** - High glucosinolate *B. juncea* meal obtained from the previously described source was applied at the basic rate of 0.45 kg/8m row. This rate was chosen because a limited amount of product was available. The meal was applied at planting and/or at the second hilling, either as dried meal or shaken into 2L of water. The meal did not dissolve completely and required shaking frequently during application. The application in water was included as a treatment because M. Chiba indicated that moisture would trigger decomposition of the meal. The meal was applied either in water or as dry meal on the top of the hill immediately before the second hilling, and was then covered by the soil mounded up during the hilling operation.

The treatments were:

1. 0.45 kg/row of meal applied at planting
2. 0.45 kg/row applied at planting, 0.45 kg applied at hilling
3. 0.45 kg/row applied at planting, 0.9 kg applied at hilling
4. 0.45 kg/row applied at planting, 0.45 kg applied in water at hilling
5. 0.45 kg/row applied only at hilling
6. 0.45 kg/row applied in water only at hilling
7. no meal applied.

Trial 2 was conducted exactly as described for Trial 1.

On August 24th, two to three hills of potatoes were dug from the beginning of each row, to obtain at least six main stems/roots. The roots were washed gently and rated for the presence of *Rhizoctonia* damage on the main stem/root, and the number of *S. subterranea* galls present on the roots. Disease levels and yield were evaluated at the final harvest as previously described.

**Results and Discussion:**

The application of different types of mustard meal at planting time in Trial 1 had no effect on either total yields or yields of marketable-size tubers. The incidence of black scurf on tubers was the only disease parameter significantly affected by the meal treatments. Significantly less black scurf occurred in the plots with no meal applied when compared with the plots treated with *B. carinata* (Table 3.3.6.4). There were no significant differences between other meals and the control plots or between the various types of meal. These results suggest there is no advantage to applying any of the meals at this rate and/or application time – particularly as application of *B. carinata* actually increased black scurf. This finding is in contrast to results from pot experiments (previous section) when the application of *B. carinata* meal reduced levels of powdery scab. The disease pressure levels for powdery scab were comparable between pot and field experiments. In the field trial an average of 75% of all tubers were infected with powdery scab, and 38% had over 5% of the surface area infected. In the pot trial almost 100% of the tubers were infected with powdery scab with an average severity of 15.8% (Table 3.3.6.2).

**Table 3.3.6.4. Effect of applying different mustard meals at planting on disease development on tubers in the field (2004).**

| Type of mustard meal incorporated at planting | Average incidence (%) of Rhizoctonia infected tubers |
|---|---|
| ***Brassica carinata*** | 75.8 a* |
| ***B. juncea* (low gc[a])** | 69.3 ab |
| ***B. juncea* (high gc, +additives)** | 68.0 ab |
| ***Sinapis alba*** | 62.5 ab |
| ***B. juncea* (high gc, -additives)** | 61.8 ab |
| ***Camelina sativa*** | 59.8 ab |
| **No meal** | 52.3 b |
| ***Coefficient of Variance (%)*** | ***21.7*** |

[a] gc=glucosinolate

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

In Trial 2 there were no significant differences between the *Rhizoctonia* scores of plants from the meal-treated and untreated plots when roots were sampled in August. However the level of *Rhizoctonia* on the main stem/root was significantly higher in the plots where meal was applied at planting plus as a liquid at hilling, when compared with plots having meal applied at planting only, at planting plus at hilling or at hilling only in water (Table 3.3.6.5).

Powdery scab gall scores of plants grown in plots with meal applied twice at the .45kg rate, at both planting and hilling, were significantly lower than for untreated plots and in plots treated at planting only (Table 3.3.6.5). This suggests that applying meal to soils infested with powdery scab may help reduce inoculum production in root galls.

**Table 3.3.6.5. The effect of time of meal application on the level of *Rhizoctonia* infection of the root/stem and the production of galls of *S. subterranea* on the roots, by August 24th 2004.**

| Timing of meal application | Average *Rhizoctonia* score/stem | Average gall score /plant |
|---|---|---|
| .45 kg/row at planting | 0.6 b* | 1.6 a |
| .45 kg/row at planting + .45 kg/row at hilling | 0.5 b | 0.6 b |
| .45 kg at planting + .9 kg/row at hilling | 1.3 ab | 1.0 ab |
| .45 kg/row at planting + .45 kg/row in water at hilling | 1.6 a | 1.1 ab |
| .45 kg/row at hilling | 1.0 ab | 1.1 ab |
| .45 kg/row in water at hilling | 0.6 b | 1.1 ab |
| No meal | 0.7 ab | 1.5 a |
| *Coefficient of Variance (%)* | *71.1* | *42.0* |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

The incidence and severity of all three soil-borne diseases was quite high in this trial. There was no effect of applying meal on the incidence of black scurf, powdery and common scab on the harvested tubers. However there were significant effects of treatments on the percentage of tubers with greater than 5 % of the surface area infected for all three diseases (Table 3.3.6.6.). Low levels of black scurf occurred on tubers grown in plots with meal applied at planting and hilling and meal applied in water at hilling. However, the highest incidence of *Rhizoctonia* infected tubers occurred when meal was applied at planting + at the double rate at hilling, suggesting there may be an optimum threshold of application.

None of the meal treatments significantly reduced the levels of common scab relative to the control.

Lower levels of powdery scab were also found when meal was applied at hilling and in water at hilling relative to the level of disease present when meal was applied at planting only. However none of the treatments were significantly different from the control treatment.

Meal application had no significant effect on total weight of tubers harvested. The highest marketable-size yields were obtained when no meal was applied (Table 3.3.6.7). A significant reduction in marketable size yield occurred when meal was applied in water at hilling, suggesting there may have been an effect of meal on tuber set. Lower disease

**Table 3.3.6.6. Effect of timing of meal application on the severity of black scurf, common and powdery scab on harvested tubers – 2004 field trial.**

| Timing of meal application | Av % tubers with >5% surface area infected with: | | |
|---|---|---|---|
| | Black scurf | Common scab | Powdery scab |
| .45kg at planting | 1.5 ab* | 16.0 b | 45.8 a |
| .45kg at planting + .45kg at hilling | 0.0 b | 29.3 ab | 32.5 ab |
| .45kg at planting + .9kg at hilling | 5.0 a | 36.8 a | 32.5 ab |
| .45kg at planting + .45kg in water at hilling | 3.0 ab | 20.3 b | 33.5 ab |
| .45kg at hilling | 4.0 ab | 24.0 ab | 22.5 b |
| .45kg in water at hilling | 0.0 b | 17.8 b | 21.5 b |
| No meal | 1.8 ab | 27.8 ab | 36.0 ab |
| *Coefficient of Variance (%)* | ***130.1*** | ***37.2*** | ***32.4*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

levels generally occurred when meal was applied in water at hilling, but a lower marketable-size yield also occurred in this treatment. The lower disease levels would compensate somewhat for the lower yield. The rows receiving the highest weight of meal, had higher disease levels for both black scurf and common scab, suggesting that the influence of rate of application on disease levels should be carefully monitored under a range of situations.

**Table 3.3.6.7. Effect of timing of meal application on marketable-size yield of tubers at harvest.**

| Timing of meal application | Marketable-size yield (kg/8m row) |
|---|---|
| .45 kg/row at planting | 24.0 ab* |
| .45 kg/row at planting + .45kg at hilling | 24.8 a |
| .45 kg/row at planting + .9kg at hilling | 22.0 ab |
| .45 kg/row at planting + .45kg in water at hilling | 23.5 ab |
| .45 kg/row at hilling | 24.1 ab |
| .45 kg/row in water at hilling | 21.5 b |
| No meal | 25.0 a |
| *Coefficient of Variance (%)* | ***9.3*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

When the final marketable yield was calculated, taking into account the grade–out due to black scurf, application of meal in water at hilling still caused a significant reduction in

final marketable yields compared with untreated plots (Table 3.3.6.8). Application of meal at planting + the double rate at hilling caused significant yield losses due to common scab grade-out. The lowest marketable yield obtained after adjustment for grade-out due to powdery scab was from plots treated with meal only at planting.

**Table 3.3.6.8. Effect of timing of meal application on marketable yield adjusted for grade–out for black scurf, common and powdery scab at harvest.**

| Timing of meal application | Marketable yield (kg/8m row) adjusted for grade-out for: | | |
|---|---|---|---|
| | Black scurf | Common scab | Powdery scab |
| .45 kg/row at planting | 24.0 ab* | 21.2 a | 14.1 b |
| .45 kg/row at planting + .45 kg at hilling | 24.8 a | 18.9 ab | 18.0 ab |
| .45 kg/row at planting + .9kg at hilling | 21.8 ab | 15.0 b | 16.0 ab |
| .45 kg/row at planting + .45kg in water at hilling | 23.4 ab | 19.9 a | 16.7 ab |
| .45 kg/row at hilling | 23.6 ab | 19.5 a | 19.9 a |
| .45 kg/row in water at hilling | 21.5 b | 18.8 ab | 17.9 ab |
| No meal | 24.8 a | 19.3 a | 17.8 ab |
| *Coefficient of Variance (%)* | ***9.0*** | ***14.0*** | ***18.0*** |

* means followed by the same letter are not significantly different (P=0.05), using the LSD test.

Screening trials are a vital first step in the development of any new pest control product. These trials can be challenging, as many of the factors that can influence the efficacy of a product (i.e. rate and timing of application, formulation, placement of product, etc.) have not been optimized. The trials reported here represented a first effort at screening mustard meal products for potential use as a biofumigant for soil-borne disease of potatoes. It appears that the meal obtained from high glucosinolate *B. juncea* has the best activity as a biocontrol agent for the pathogens evaluated at the trial site. This product could be applied to the soil at planting or hilling at fairly high rates with minimal toxicity to the crop. Results obtained under the more controlled growth cabinet conditions differ from the results obtained in the field. Further work is needed under both controlled and field conditions to accurately assess the value of applying mustard meal as a biocontrol agent.

Additional ADF funding has been allocated to continue studying the potential for mustard meal products to act as biocontrol agents (ADF Project # 20040548: Industrial Bioprocessing of High Glucosinolate Cruciferous Plants).

### 3.4. Conclusions

The trials conducted in this project indicate that **irrigation management** is an effective and relatively easily managed tool with potential for reducing the impact of common and powdery scab, at least under small-plot conditions. Increasing irrigation at tuber set was

effective at reducing grade-out due to common scab, while losses to powdery scab were reduced under drier conditions. The degree of scab control achieved by manipulating the irrigation regime varied somewhat from year to year – reflecting variations in growing conditions and disease pressure. The extent of scab damage and irrigation responses also varied between cultivars – this likely reflects subtle differences in the overall disease sensitivity of the tested cultivars, as well as differences in their developmental stage when the irrigation regimes were applied.

The results generated in this trial suggest that it is very important that producers correctly identify the particular pathogen prevalent in their field, before choosing an irrigation management strategy for control of disease. While increasing irrigation at tuber set may reduce the severity of common scab, it can exacerbate problems with powdery scab. When reducing irrigation at tuber set is considered as a means to reduce powdery scab, the impact of this treatment on yields must also be considered.

Knowledge of the **susceptibility of different cultivars** to disease is important. Disease reactions should be studied over a number of years, utilizing production practices that reflect the industry norm. In trials conducted from 2003-2005, the relative disease responses of a range of cultivars were tested in nursery plots with a very high level of soil-borne disease. The cultivars selected for testing represented cultivars of local market importance known to vary in their yield potential, growth habit and disease sensitivity. In the 2004 trial Norland was the only cultivar that developed appreciable levels of powdery scab, but both Norland and AC Peregrine formed significant numbers of powdery scab galls on the roots. This suggests that AC Peregrine may be preferred as red-skinned cultivar on sites infested with powdery scab. It also suggests that powdery scab inoculum pressure will increase even if AC Peregrine is grown – as the roots of AC Peregrine support development of the spore-laden galls. Norland appeared much less sensitive to common scab than AC Peregrine. Of the Russet-type cultivars tested, Gem Star and Russet Burbank appeared less sensitive to both types of scab than Russet Norkotah. Gemstar was also quite resistant to black scurf. The combination of high levels of disease tolerance plus good yields and processing quality suggests that Gem Star represents a very promising new variety. Selection of cultivars by producers is usually market driven but knowledge of the reaction of cultivars to disease pressure is an important tool for making economically viable choices.

None of the presently registered **chemical control products** tested as either seed piece applied or in-furrow treatments reduced levels of common or powdery scab. However, in-furrow and at hilling applications of two non-registered fungicides (Ranman and Blinex) appeared to reduce both the incidence and severity of infection by both scab organisms. It should be emphasized that these data are from a single growing season – and will need to be confirmed in subsequent testing. Azoxystrobin (Quadris) applied in-furrow reduced the incidence of black scurf (*Rhizoctonia*) on the harvested tubers. Azoxystrobin is registered for control of *Rhizoctonia* stem canker but the data generated in this trial suggests that the control is carrying through to harvest. Dithane applied in furrow also showed some promise for *Rhizoctonia* control – a label expansion to cover in-furrow application of dithane for control of *Rhizoctonia* should be considered.

The research literature suggests that **green manuring** can be utilized as part of an integrated management program for a range of soil-borne pests. Growing conditions, pest pressure, timing of application, green manure crop type and growth stage all have the potential to influence the efficacy of a green manure program. In areas with a short growing season like Saskatchewan, fall cropping will only produce a limited biomass of the green manure crop – therefore green manure crops will likely need to be established in the year prior to when the potato crop is grown. As there is no economic return from this plough down crop, green manuring will represent a considerable expense to the grower. The benefits will therefore have to be quite substantial.

In a test where a green manure crop was established and planted into in the spring, there were signs of the green manure crop having some disease suppressing effects. The limited response likely reflects the limited biomass of the green manure crop. When a potato crop was planted into land that received the residues generated by an entire season's growth of green manure crops, some disease suppression was observed but the effects were limited and/or inconsistent. The level of disease control achieved in these green manure trials would not be sufficient to justify the effort or expense in establishing and maintaining the green manure crops. However, these results reflect one evaluation of a limited range of green manures at one site and further evaluation is recommended.

Soil-borne rather than seed-borne inoculum was more effective for generating disease under growth chamber conditions. In growth cabinet trials, there were indications that incorporation of *L. multiflorum* as a green manure may reduce *Rhizoctonia* levels and that *B. juncea* may reduce powdery scab. The results from the growth cabinet studies were highly variable possible due to variable pathogen inoculum levels.

Incorporation of **mustard meal** may represent a method for achieving the disease-control benefits of green manuring without having to devote an entire cropping season to producing the green manure crop. Preliminary growth chamber experiments indicate that meals from different species may either increase or decrease disease levels. Evaluation of different mustard meals incorporated into field plots indicated there were no phytotoxic effects of the different meals. The meal treatments did not significantly affect disease levels, except for an increase in black scurf when *B. carinata* meal was applied.

When the effect of applying *B. juncea* meal to field plots at different times and rates was evaluated, the treatments had obvious effects on disease levels – but the effects were not consistent. Further testing is necessary to evaluate the potential for use of mustard meals as disease control agents.

## 4. EQUIPMENT

No capital expenditures.

## 5. PROJECT DEVELOPED MATERIALS

Poster:

Thomson, Jill & Doug Waterer. Impact of irrigation management on development of powdery and common scab. Annual meeting of Potato Association of America, Scottsbluff, Nebraska. 8-11 August 2004.

Presentations:

Thomson, Jill & Doug Waterer. Potato disease control using green manure. Annual meeting of Potato Growers of Alberta, Red Deer, Alberta. 19 November 2004.

Thomson, Jill & Doug Waterer. Irrigation management strategies for control of scab of potatoes. Regional meeting of Canadian Phytopathological Society, Saskatoon. 23 November 2004.

## 6. PROJECT PHOTOS

Included with report as separate file.

## 7. ACKNOWLEDGMENT

In poster:

Thomson, Jill & Doug Waterer. Impact of irrigation management on development of powdery and common scab. Annual meeting of Potato Association of America, Scottsbluff, Nebraska. 8-11 August 2004.

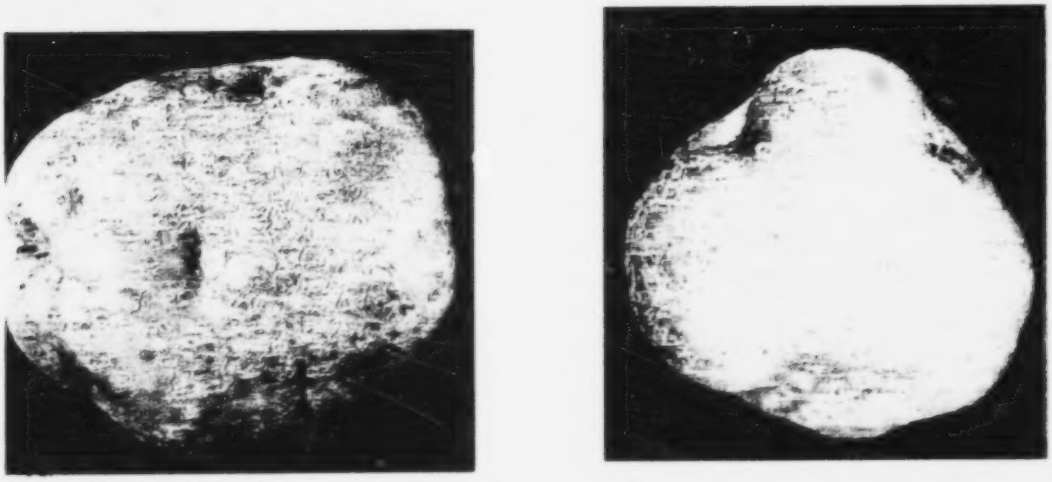
In presentations:

Thomson, Jill & Doug Waterer. Potato disease control using green manure. Annual meeting of Potato Growers of Alberta, Red Deer, Alberta. 19 November 2004.

Thomson, Jill & Doug Waterer. Irrigation management strategies for control of scab of potatoes. Regional meeting of Canadian Phytopathological Society, Saskatoon. 23 November 2004.

## 8. EXPENSE STATEMENT

Prepared by Research Accounts, University of Saskatchewan. Sent as separate email attachment.



A. B.

**Figure 3.1.1.** Tubers infected with A) powdery scab (*Spongospora subterranea*) and B) common scab (*Streptomyces scabies*).

**Figure 3.1.2.** Tubers infected with black scurf (*Rhizoctonia solani*).

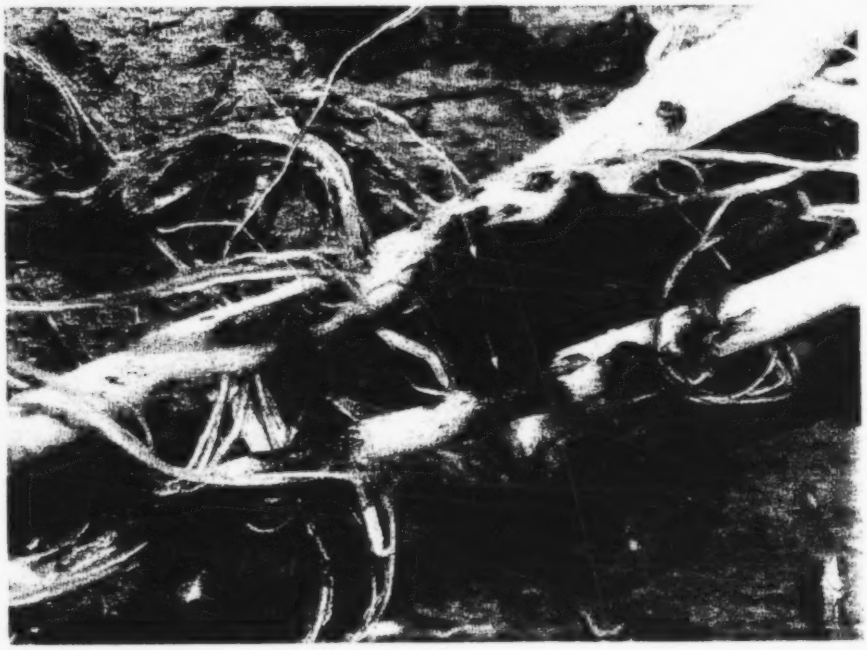


**Figure 3.1.3.** Underground potato stems infected with *R. solani.* Arrows indicate lesions destroying stem tissue.

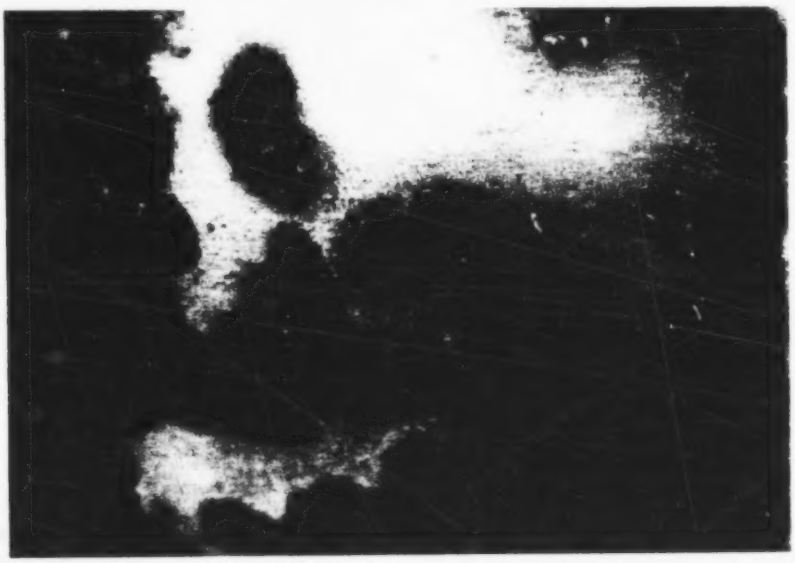


**Figure 3.1.4.** Tubers infected with powdery scab. Masses of resting spores (cystosori) in scab lesions.

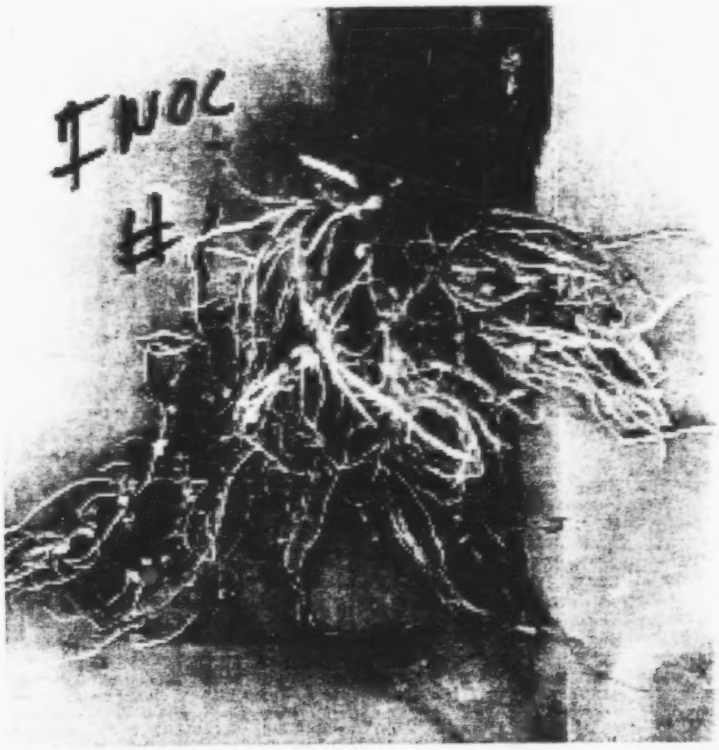



**Figure 3.1.5.** Galls on potato roots, caused by powdery scab infection.

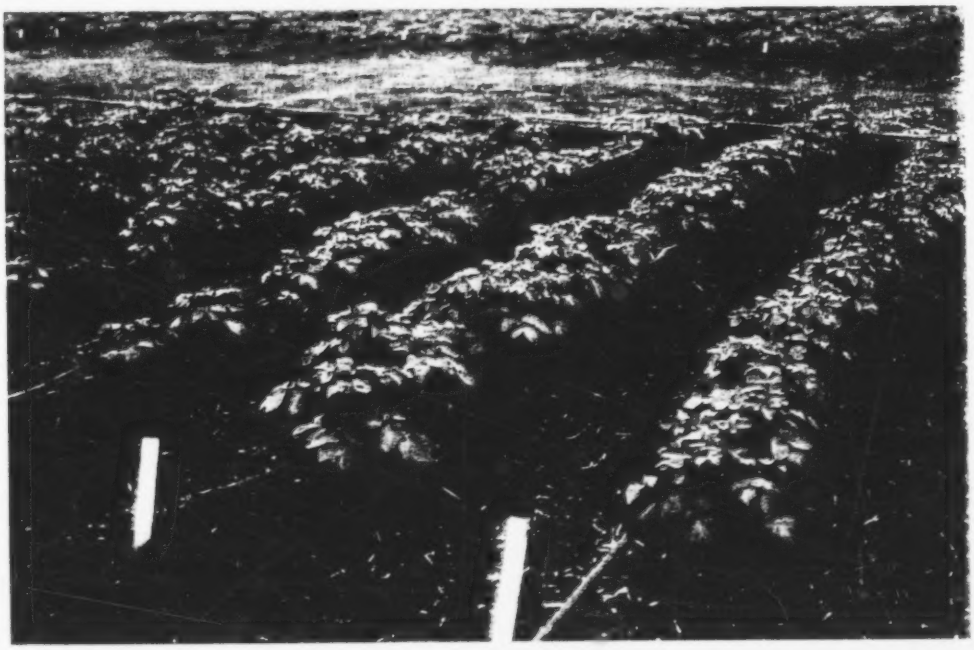


**Figure 3.3.1.1.** Irrigation trial, June 2004. Drip lines were laid on top of hills. Double lines were used for treatments with reduced or increased irrigation at certain times.

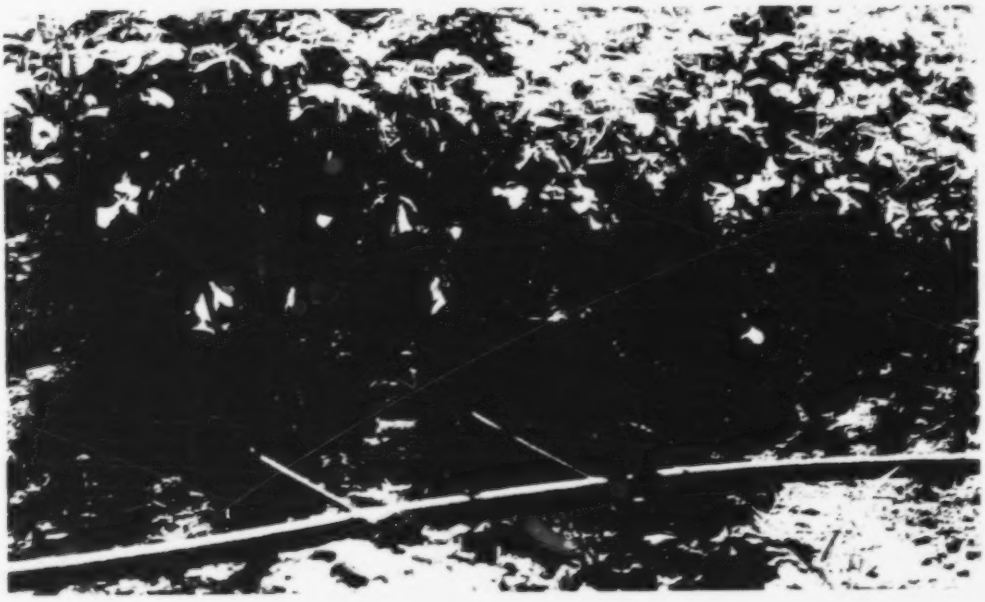


**Figure 3.3.1.2.** Irrigation trial, August 2004. Main feed line, with two drip lines running along the top of the hill.

**Figure 3.3.4.1.** Incorporation of green manure crop during potato planting, 2003.

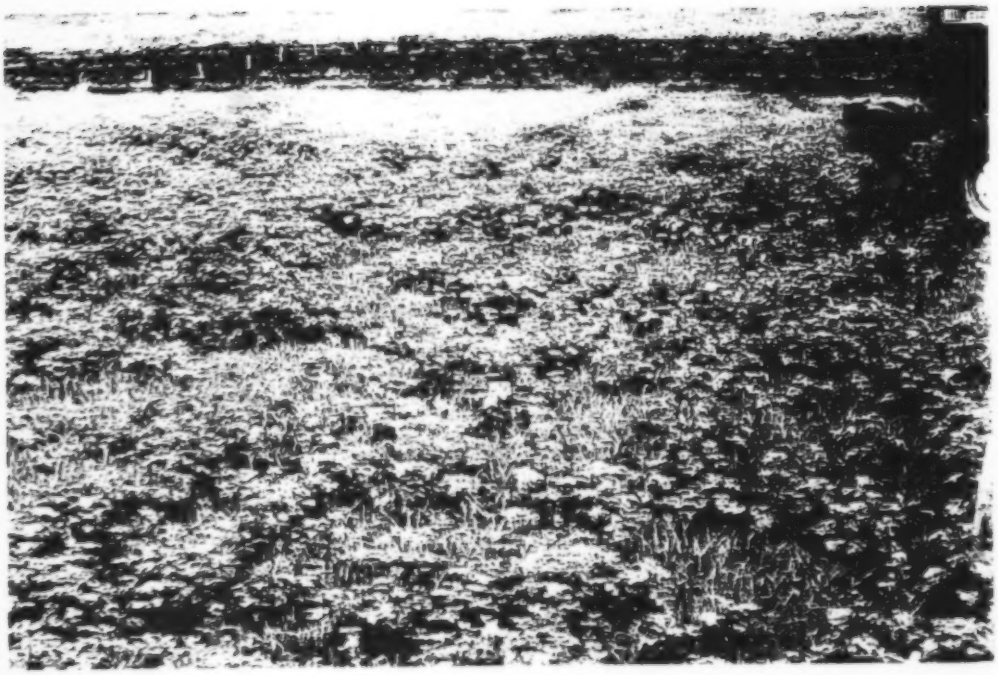


**Figure 3.3.4.2.** Establishment of *Sinapis alba* crop (seeded April 24,2003) by 6 June 2003.

**Figure 3.3.4.3.** Green manure plots before cutting and cultivating in August 2004. Plots from left to right: *B. juncea*, *B. napus*, *S. alba*.

**Figure 3.3.5.1.** *Brassica* species, cut into 2 cm lengths, ready for incorporation into potting soil, June 2004 .

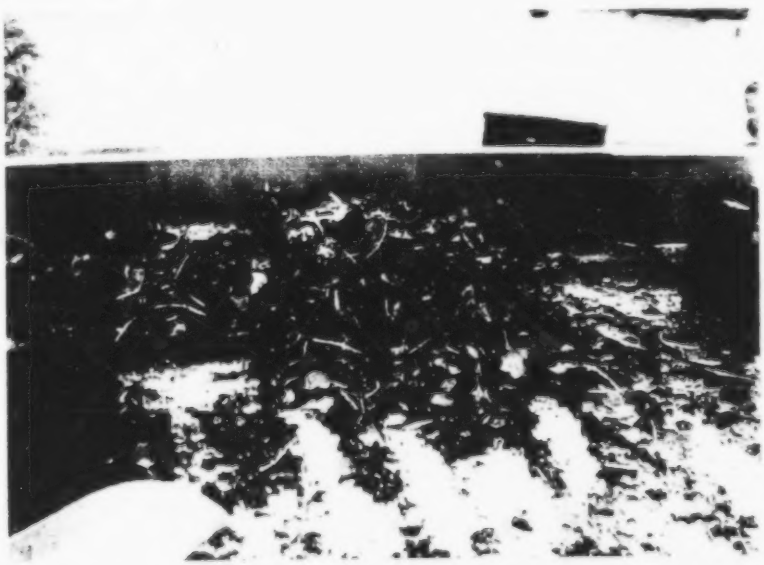


**Figure 3.3.5.2.** Mixture of green manure and soil, ready for potting and planting, June 2004.